Automated Detection of Non-Termination and `NullPointerExceptions` for Java Bytecode

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Automated Non-Termination Analysis

- Logic programs:
  De Schreye '90 ..., Payet & Mesnard '06, ...
- TRSs and SRSs:
  Giesl et. al '05, Payet '06, ...
- C:
  Gupta et. al '08, ...
- JBC:
  Velroyen '08, Payet & Spoto '09

The example

```
class Loop {
 void main(String[] a){
  int i = 0;
  int j = a.length;
  while (i < j) {
   i += a[i].length();}}}
```

1. Adds up lengths.

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3. May throw `NullPointerExc`

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05: iload_1         #load i to stack
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Abstract JAVA virtual machine states

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$00 \mid \mathtt{a}:a_1 \mid \varepsilon$
$a_1{:}\mathtt{String}[\,]\ i_1 \qquad i_1{:}[\geq 0]$

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a_1:String[] i_1 i_1:[$\geq$0]

stack frame:

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stack frame:

- Next program instruction

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stack frame:

- Next program instruction
- Local variables
- Operand stack

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heap information:

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a_1 : String[ ] i_1 $\quad$ i_1 : [$\geq$0]

stack frame:

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heap information:

- at a_1 is String array content unknown, length is i_1

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- Unknown `String` object: `String(?)`

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Only explicit sharing

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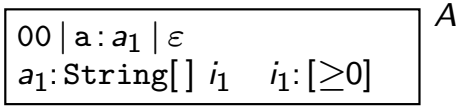

State A:

- What can happen when evaluating `main`?
- a_1: Unknown array of `String` objects
- i_1: a_1's unknown length

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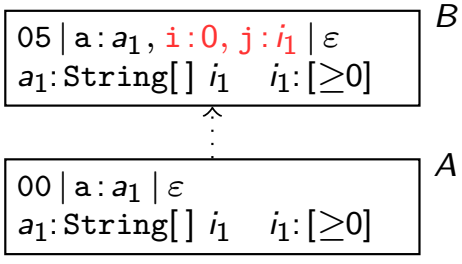

State B:

- Stored 0 to i
- Stored arraylength i_1 to j
- *Evaluations* from A to B

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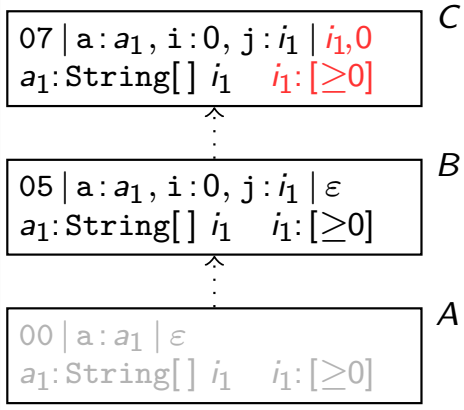

State C:

- Load `i` (0) and `j` (i_1) to operand stack
- `if_icmpge` cannot be evaluated

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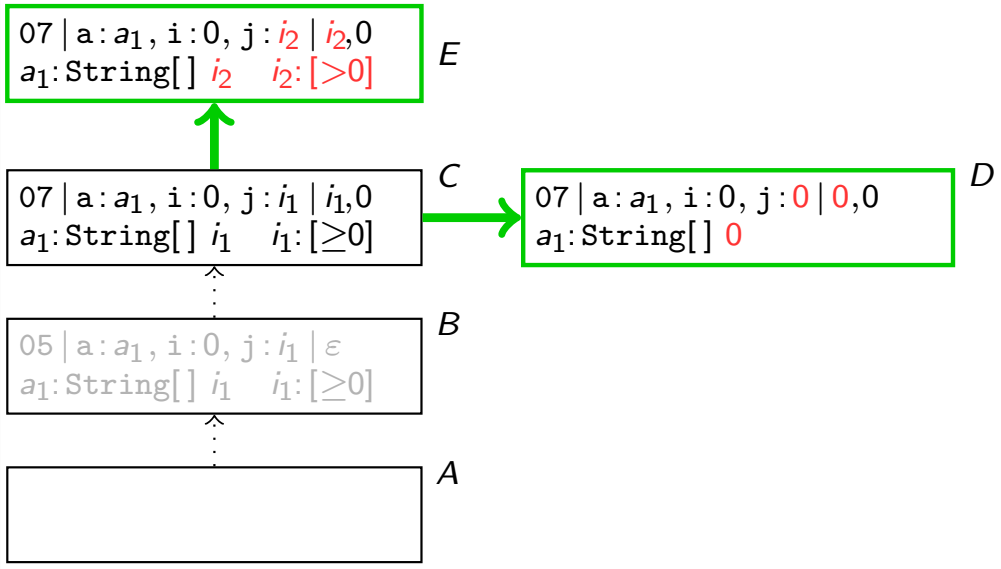

State C, D, E:

- Load `i` (0) and `j` (i_1) to operand stack
- `if_icmpge` cannot be evaluated yet:

$\Rightarrow$ *Refine* information:

- In D, consider case $i_1 = 0$
- In E, consider case $i_1 > 0$

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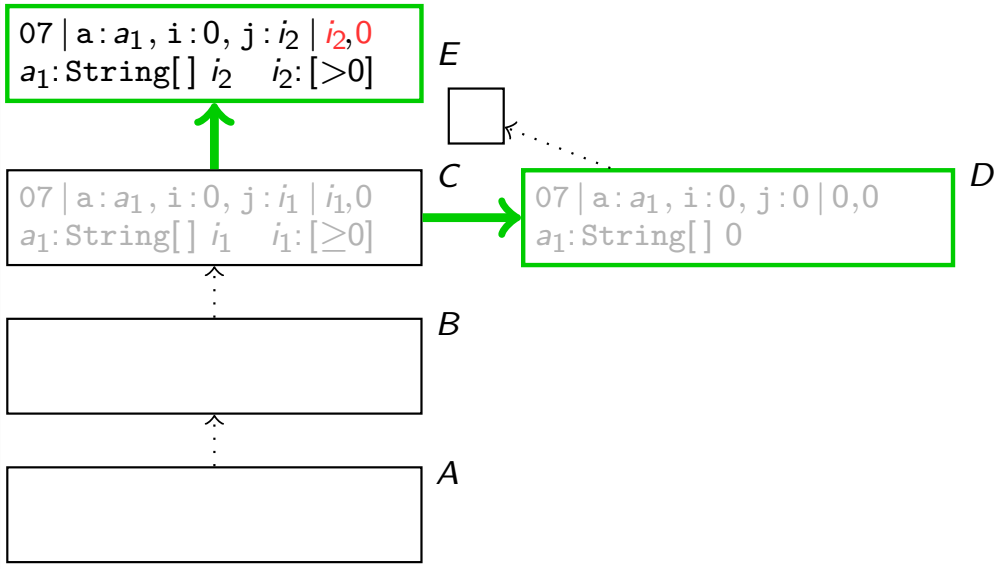

States D, E, F:

- D jumps to end of method

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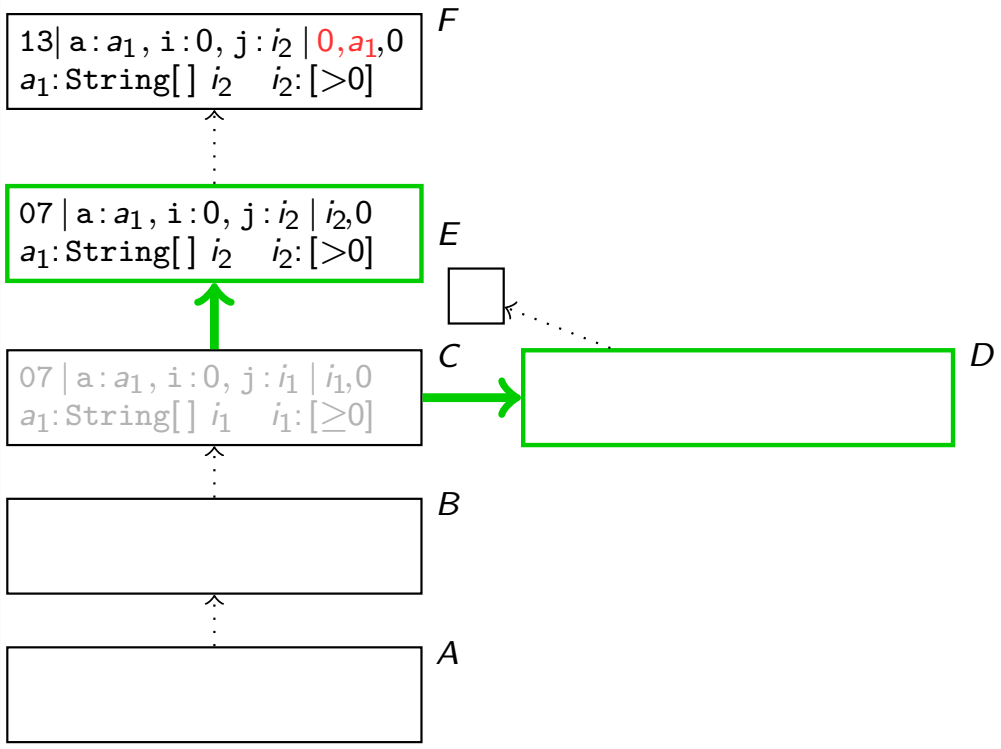

States D, E, F:

- D jumps to end of method
- E evaluates to F
- Loads array a (a_1) and index i (0) to stack
- Cannot evaluate aaload: $a_1[0]$ not known

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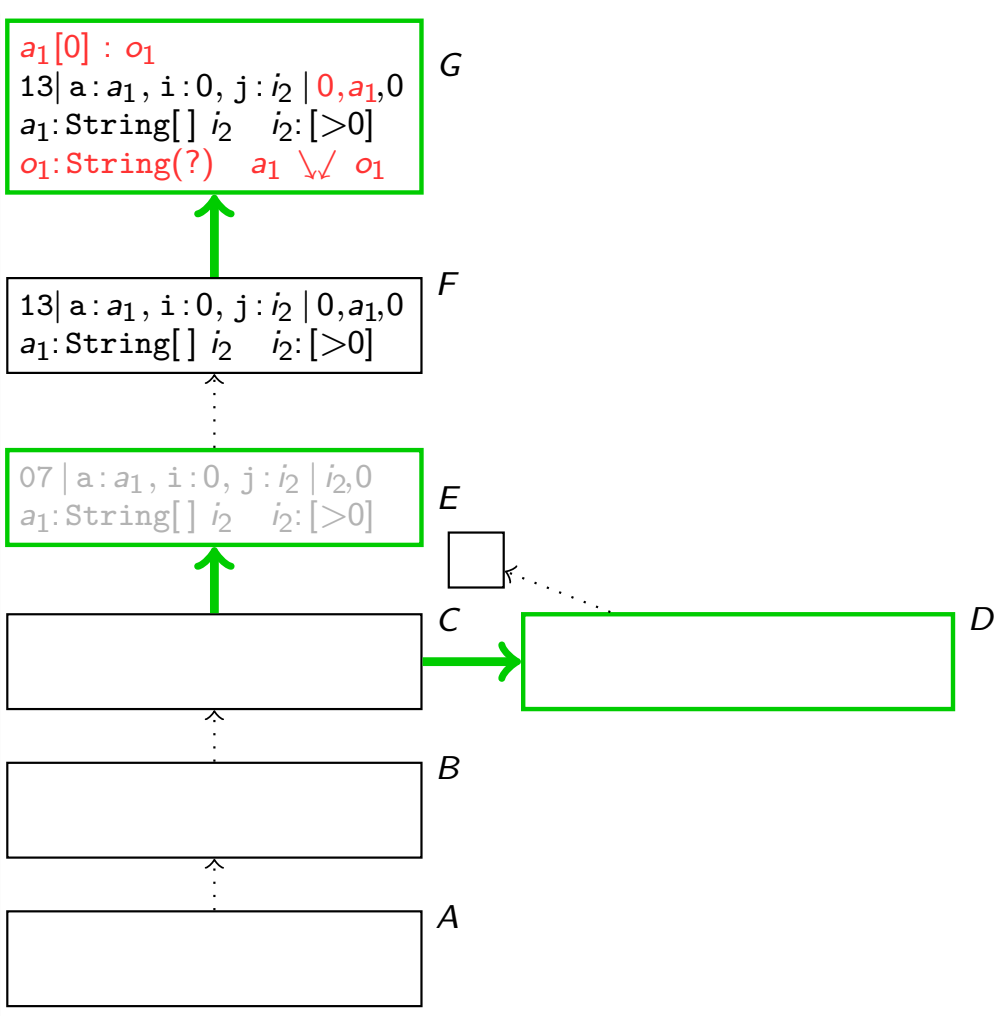

State G:

- *Refinement* of F
- o_1 created: `null` or unknown `String`
- $a_1 \curlyvee o_1$: They *share*
- o_1 is value at $a_1[i_2]$

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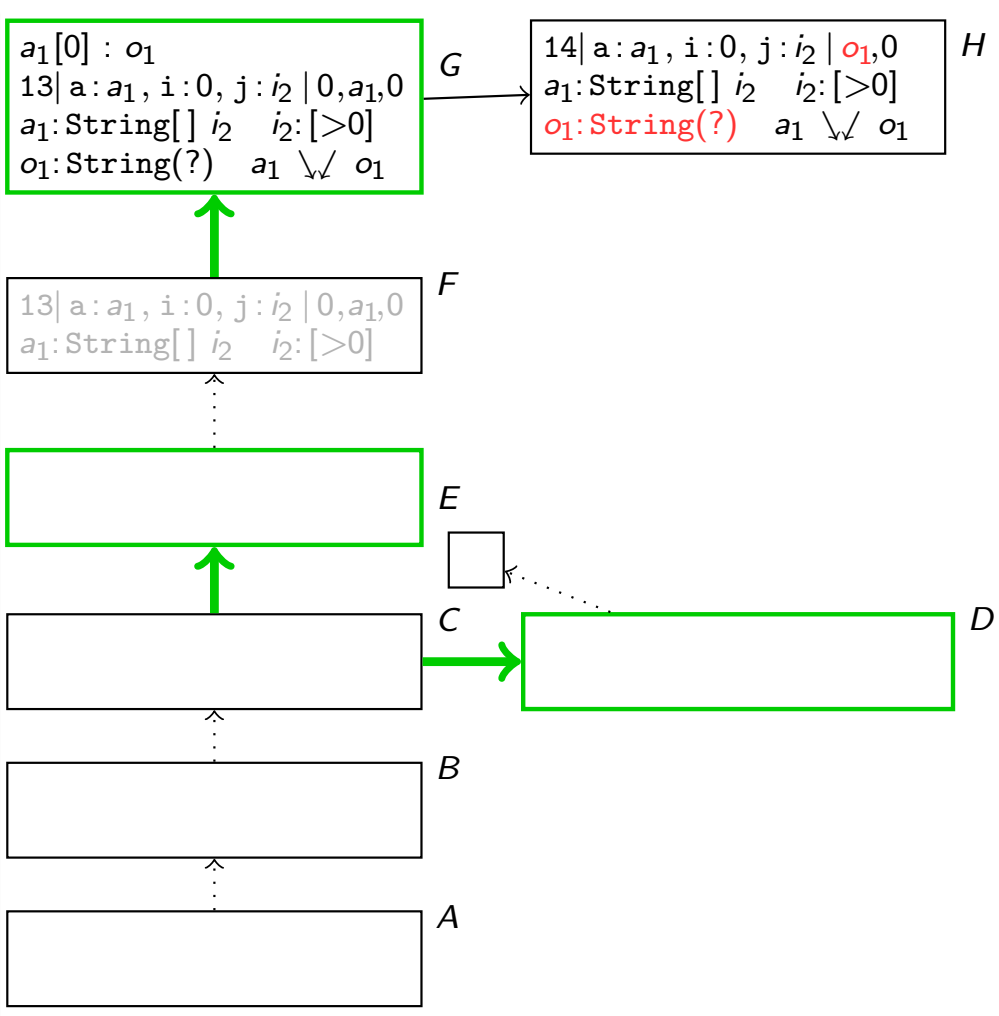

States H to K:

- H evaluated from G, loaded o_1 to stack
- `invoke` may throw `NullPointerException`

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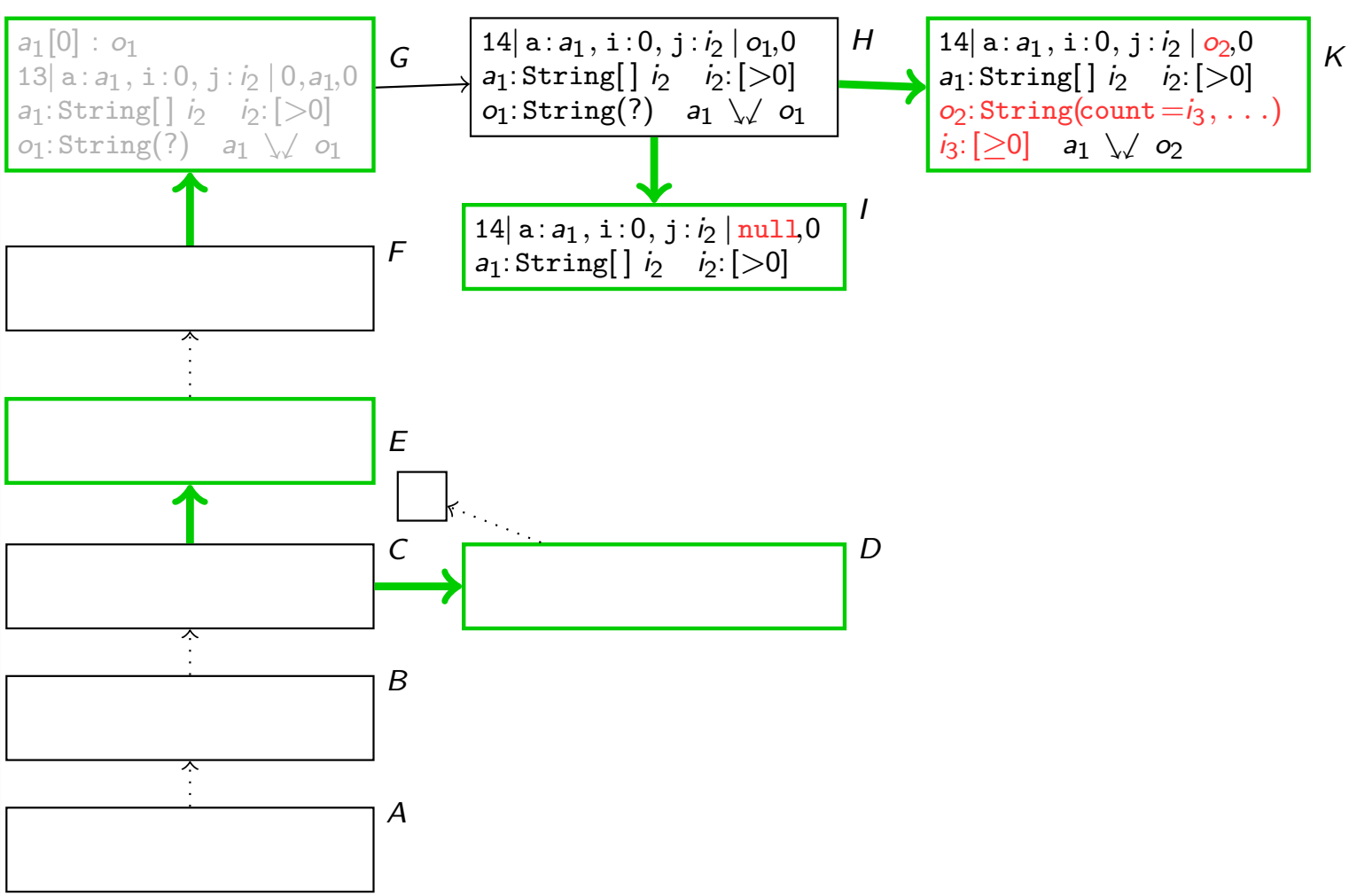

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⇒ *Refinement*:

- I: Case o_1 is `null`
- K: Case o_1 is some object with fields

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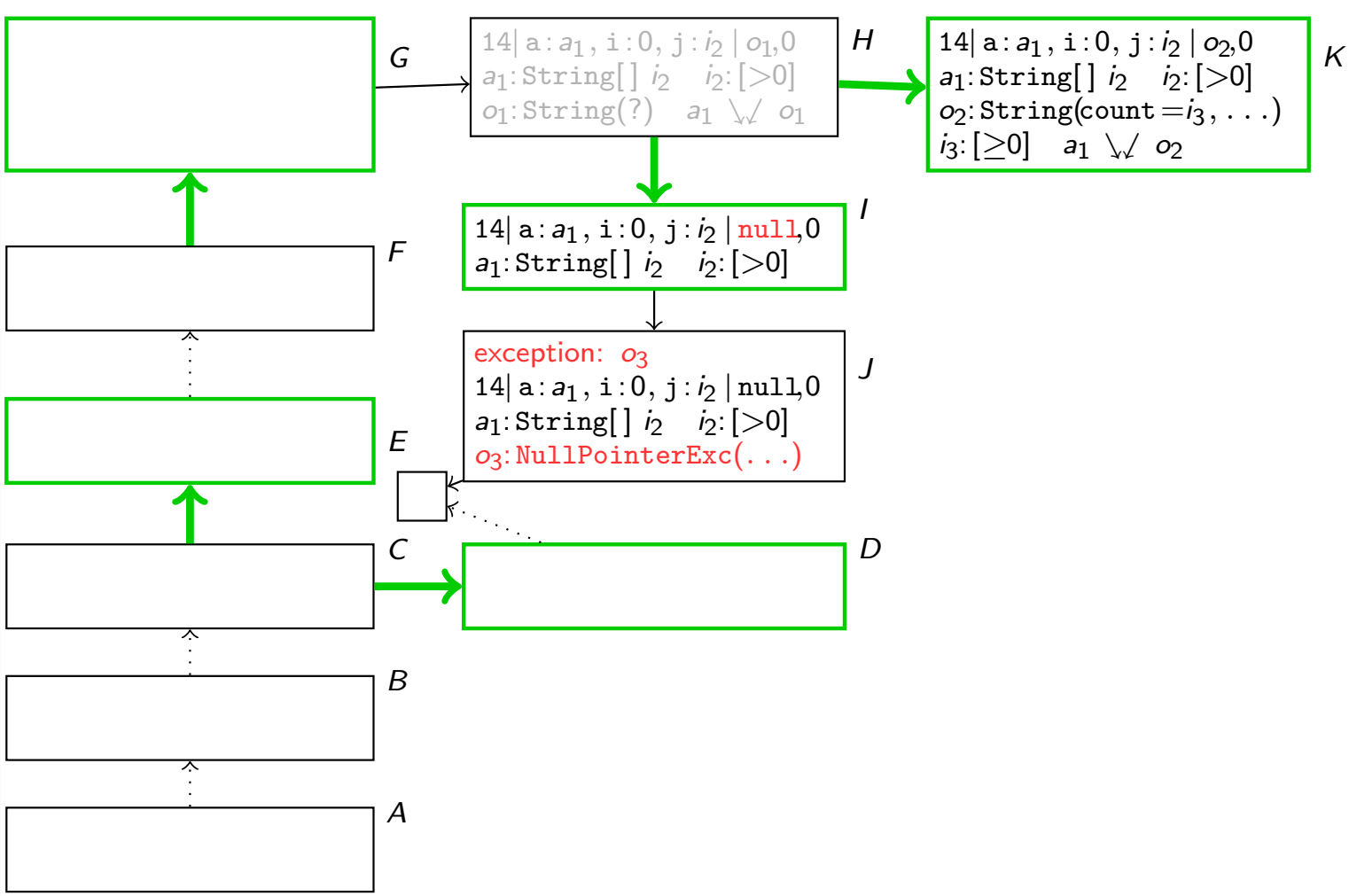

States H to K:

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$\Rightarrow$ *Refinement*:

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- K: Case o_1 is some object with fields

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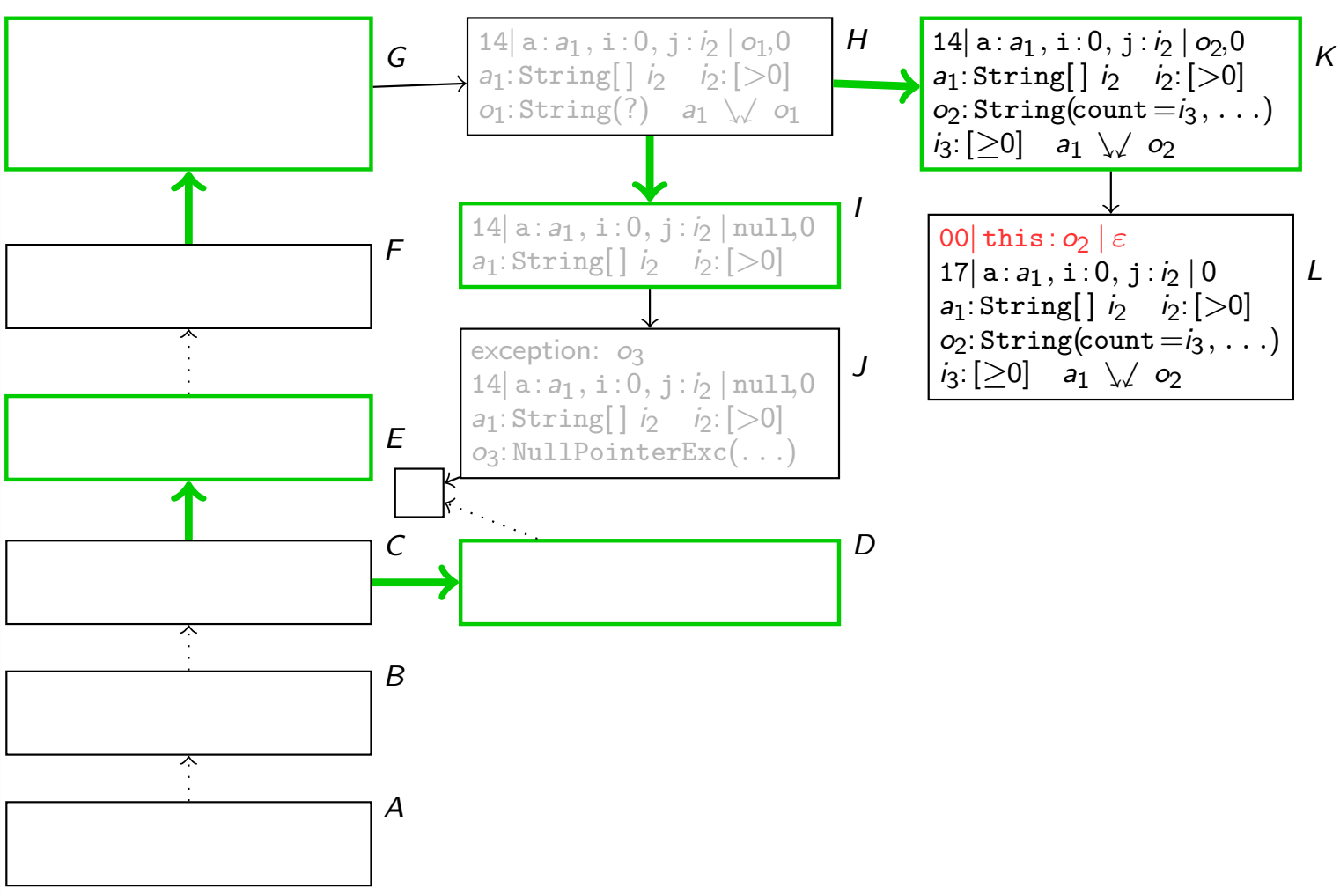

State L, M, N:

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 length():
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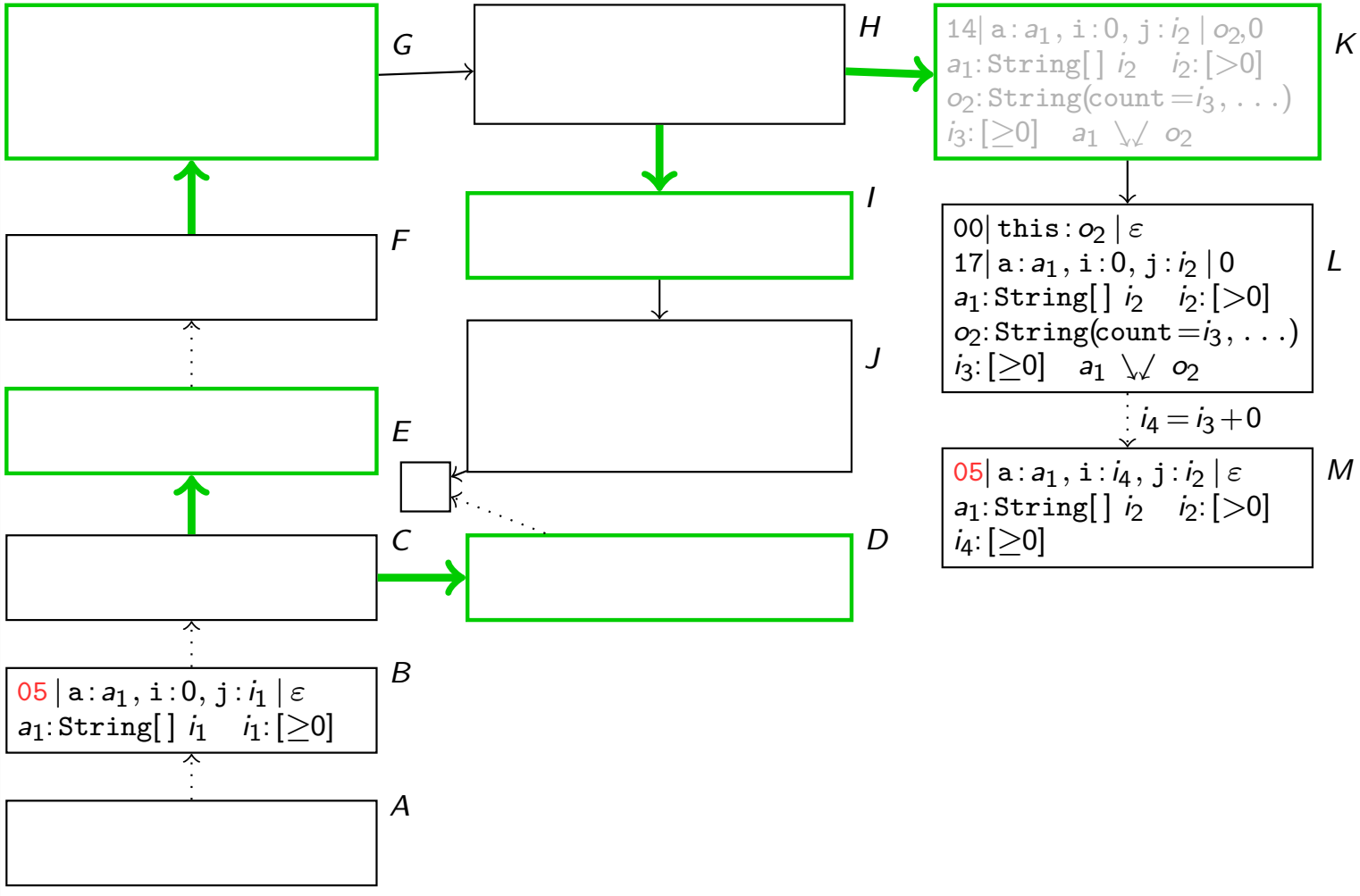

State L, M, N:

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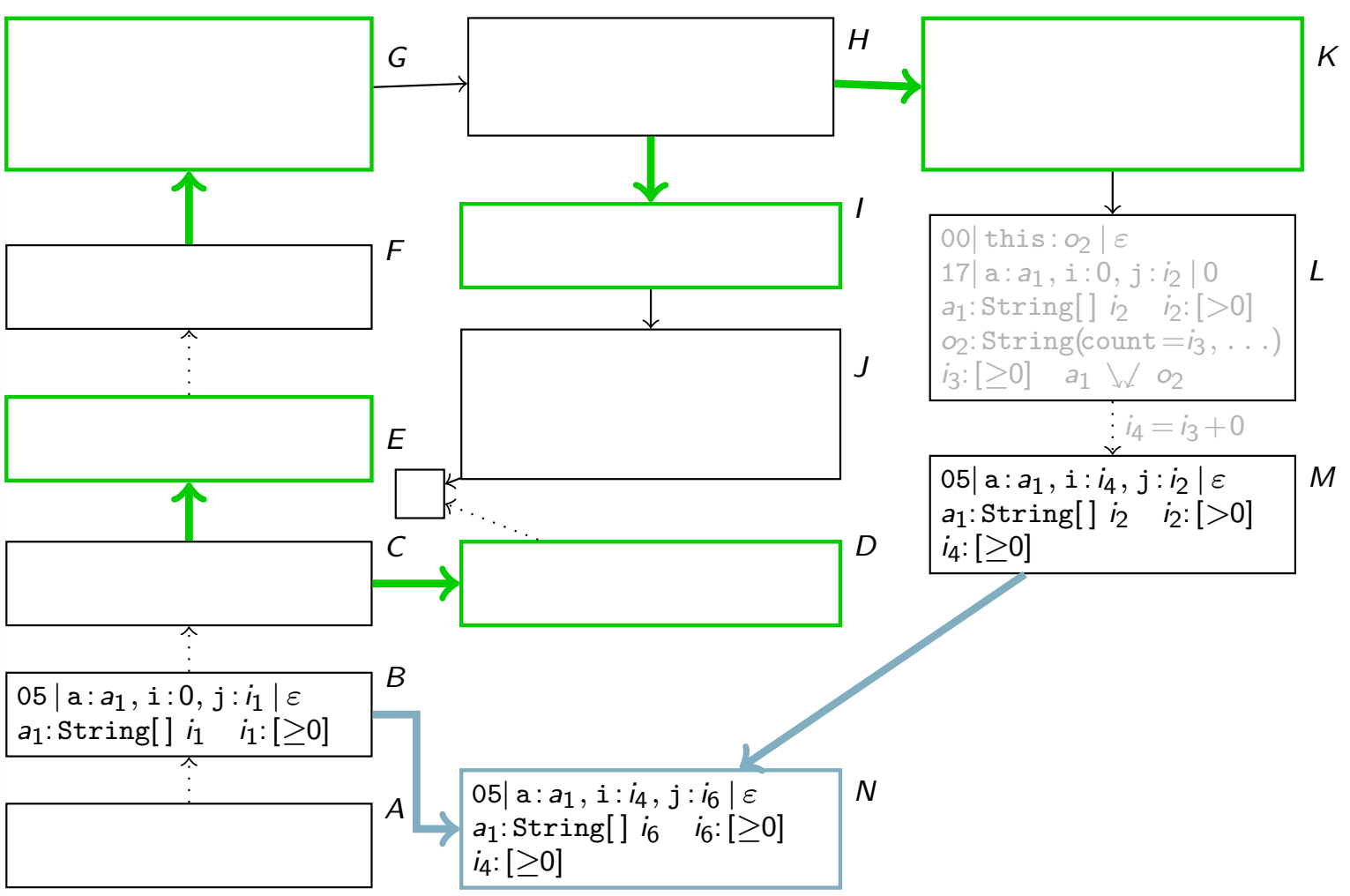

State L, M, N:

- Evaluation to L: New stack frame on top
- Evaluation to M: Retrieve length, add to i
- B and M similar: *Merge* states, get N
- N represents both B and M (*instances* of N)

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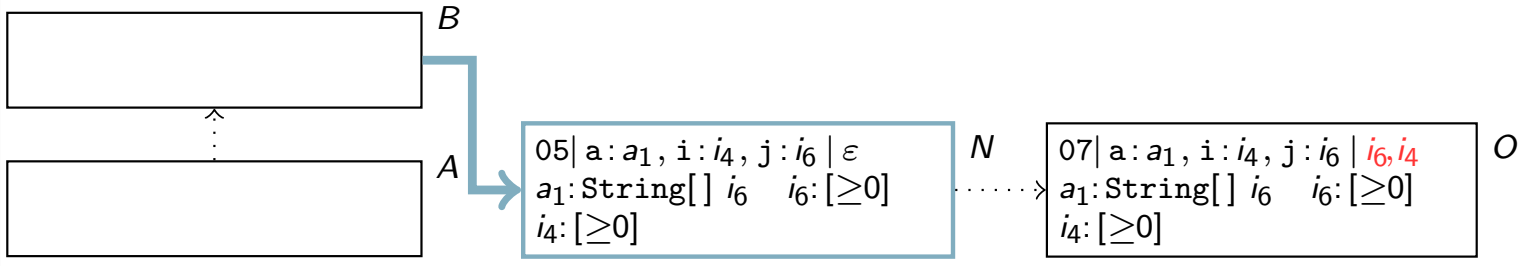

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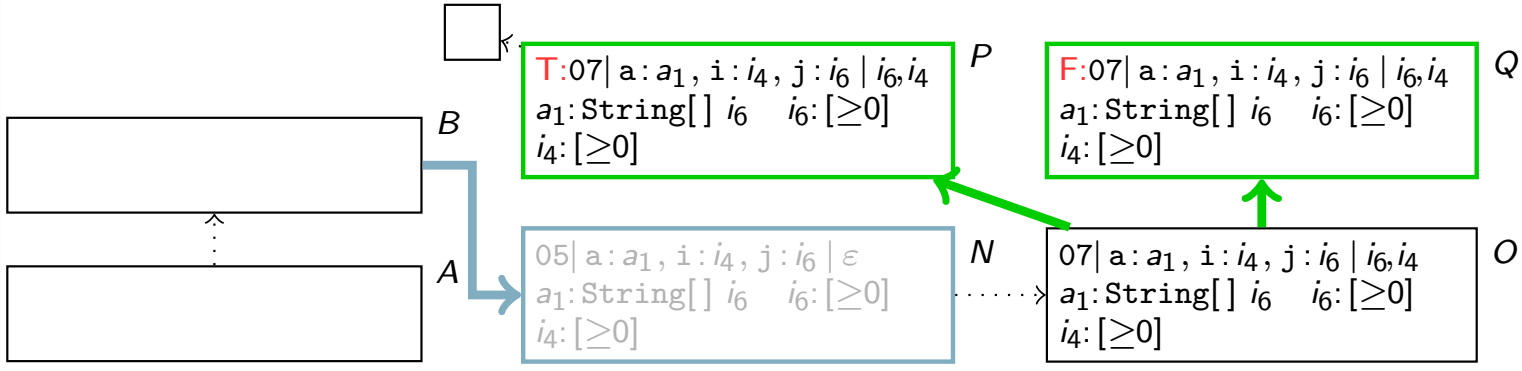

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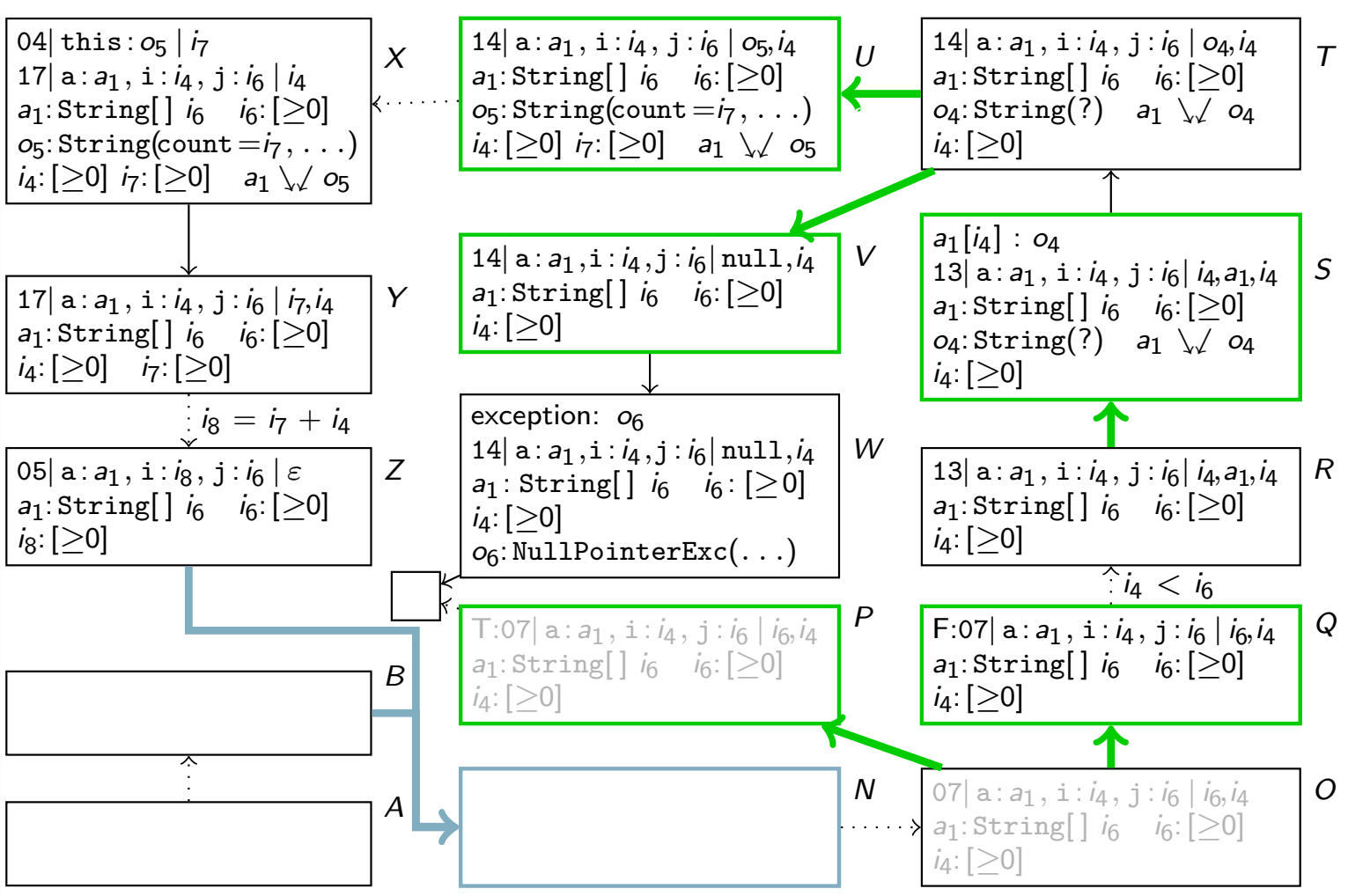

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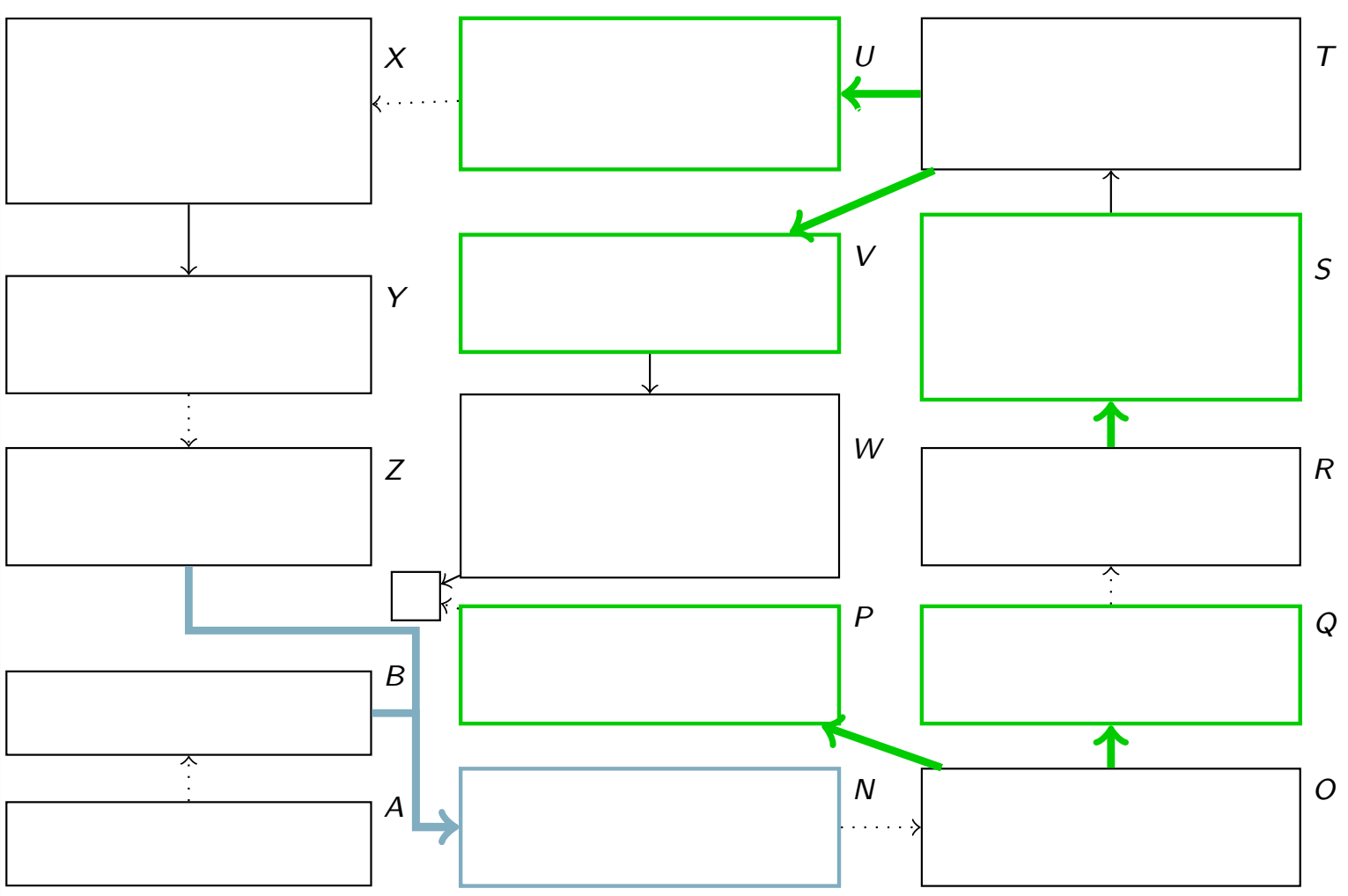

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- Refine O to P, Q: Decide result of `if_icmpge`
- Rest as before
- All leaves program ends $\Rightarrow$ construction finished

Termination graph construction

1. Choose (abstract) start state

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   - symbolic evaluation
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   until all leaves are program ends
3. Recursion and modularity supported (cf. RTA'11)

Witness generation

- Termination graphs are *over*approximations of all runs

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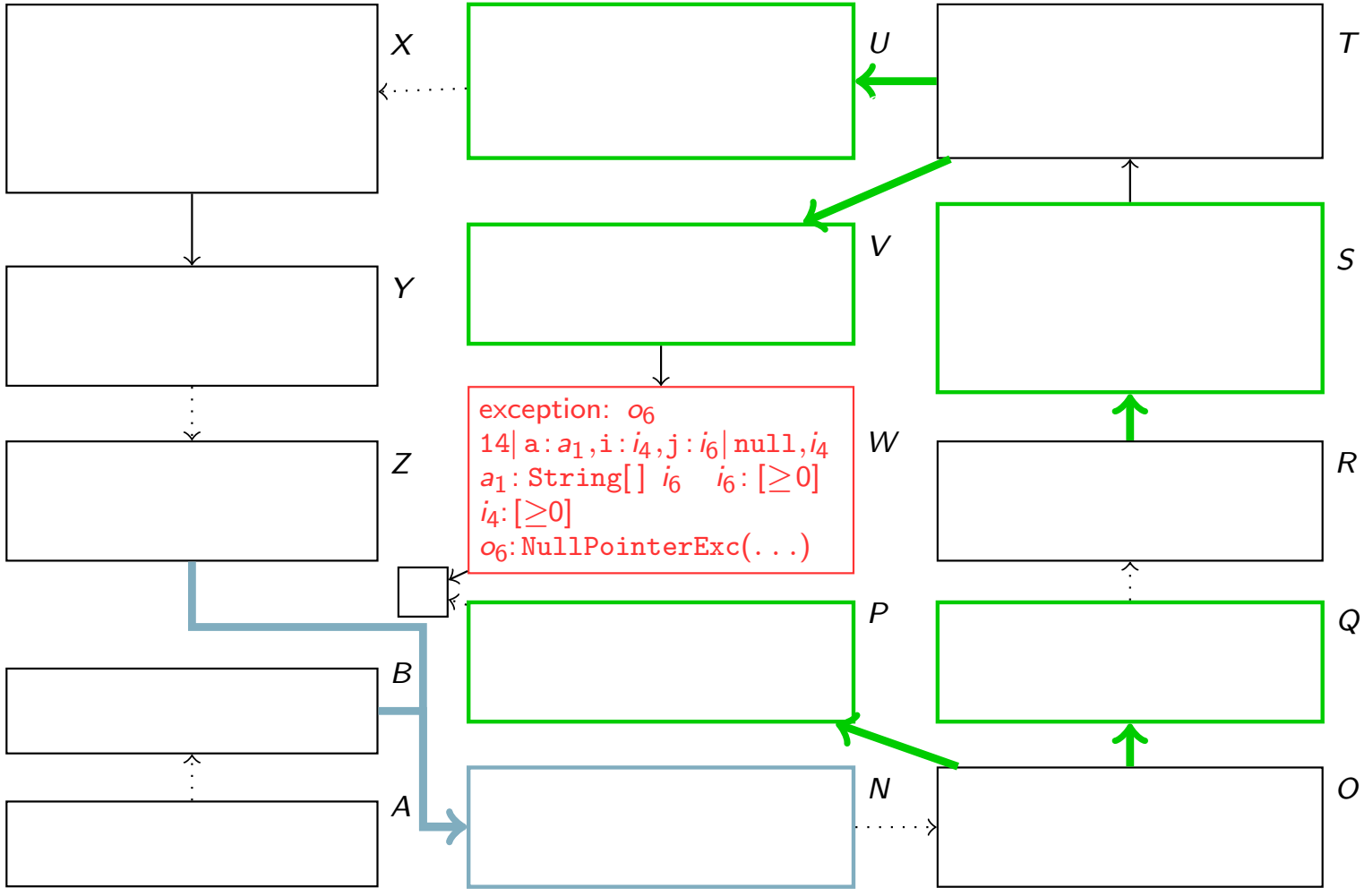
Re-use graph: Traverse edges backwards

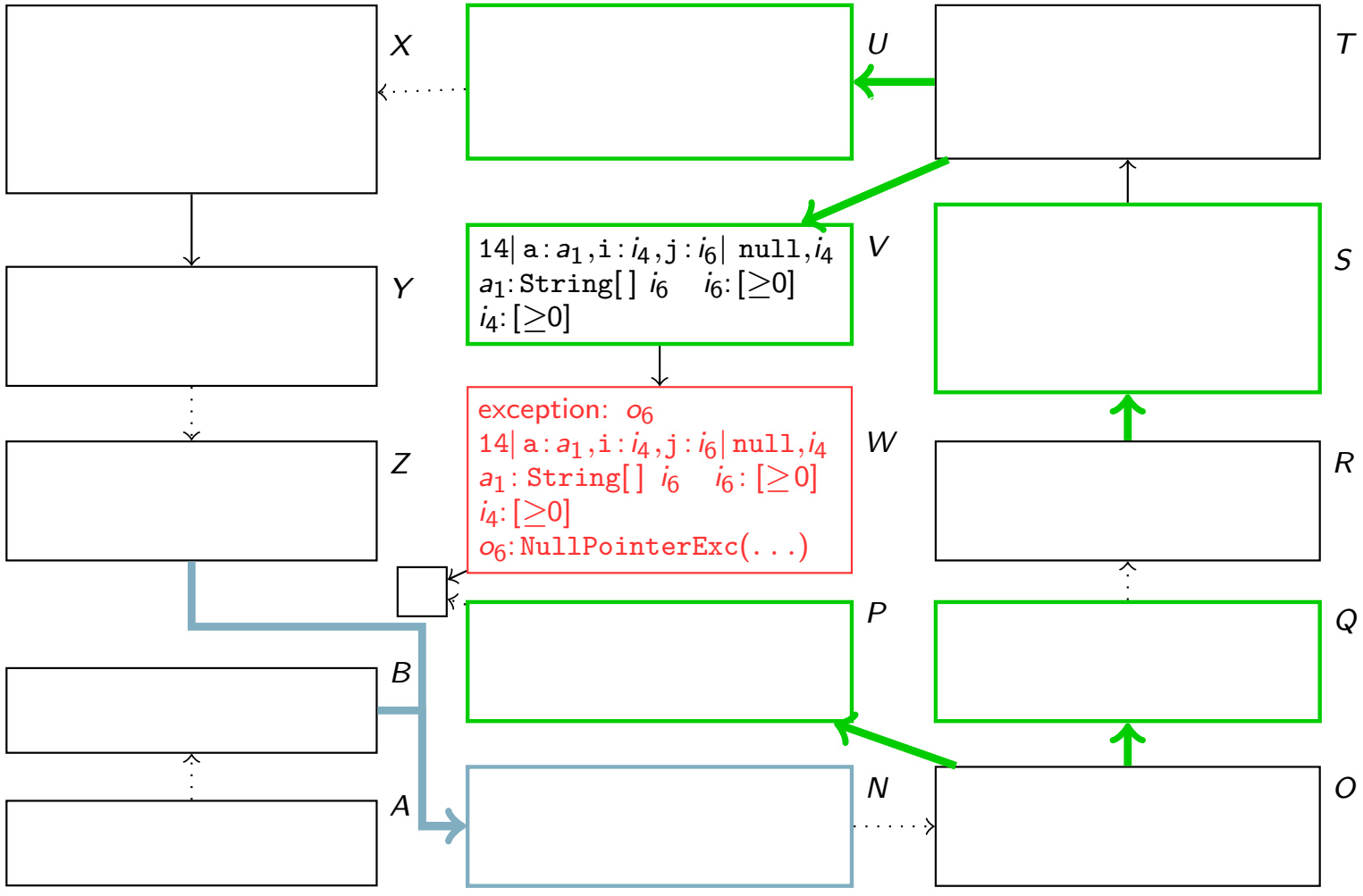


- W: program ends with a `NullPointerException`

$\Rightarrow$ Find witness

Witness for W

exception: o_6
$14|\,\mathtt{a}:a_1,\mathtt{i}:i_4,\mathtt{j}:i_6|\,\mathtt{null},i_4$
a_1 : String[ ] i_6 i_6 : $[\geq 0]$
i_4: $[\geq 0]$
o_6: NullPointerExc(. . .)



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exception: o_6
14| a : a_1 , i : i_4 , j : i_6 | null , i_4
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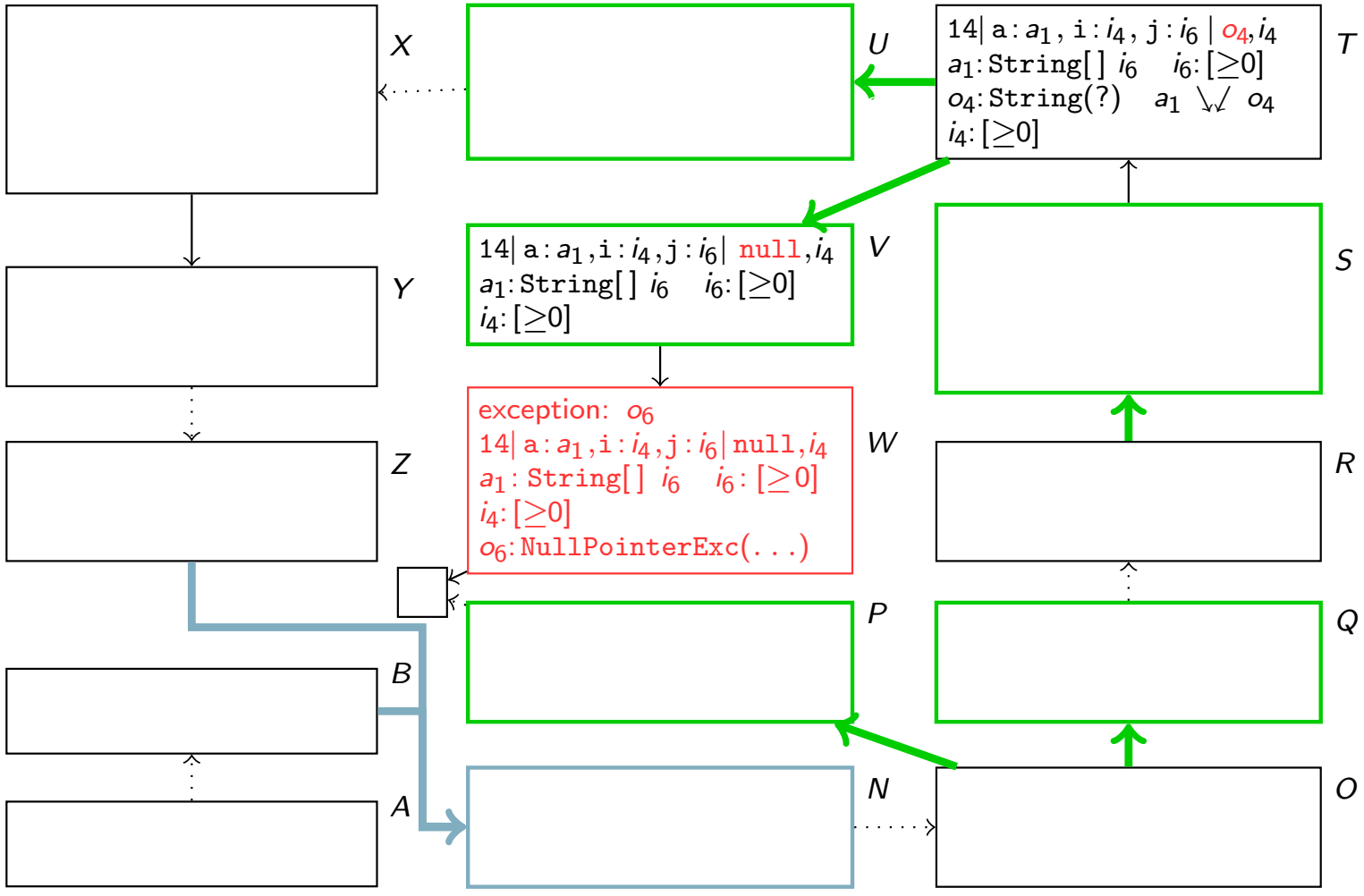
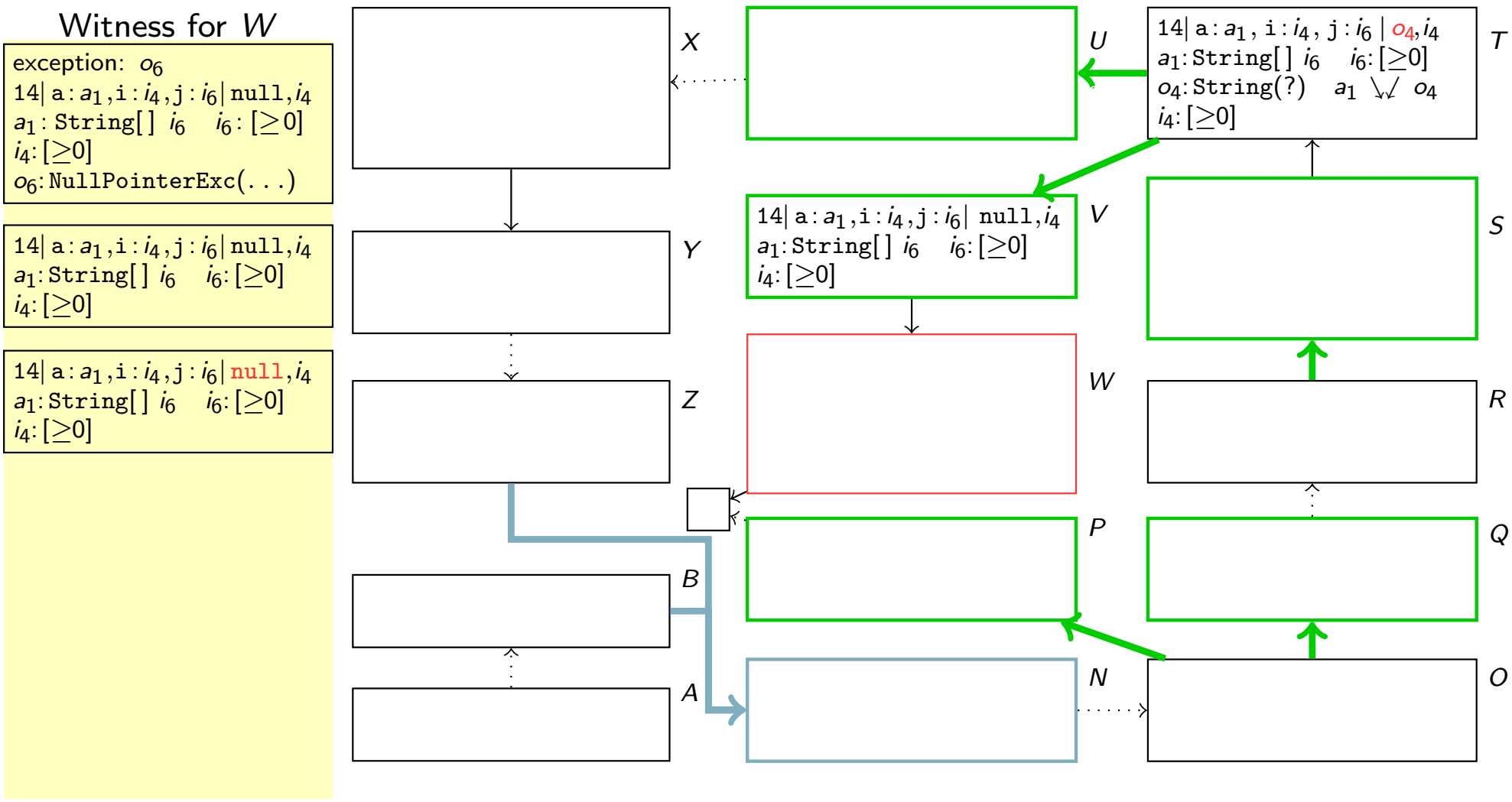


- V evaluated to W

$\Rightarrow$ Reverse evaluation step

- T refined to V



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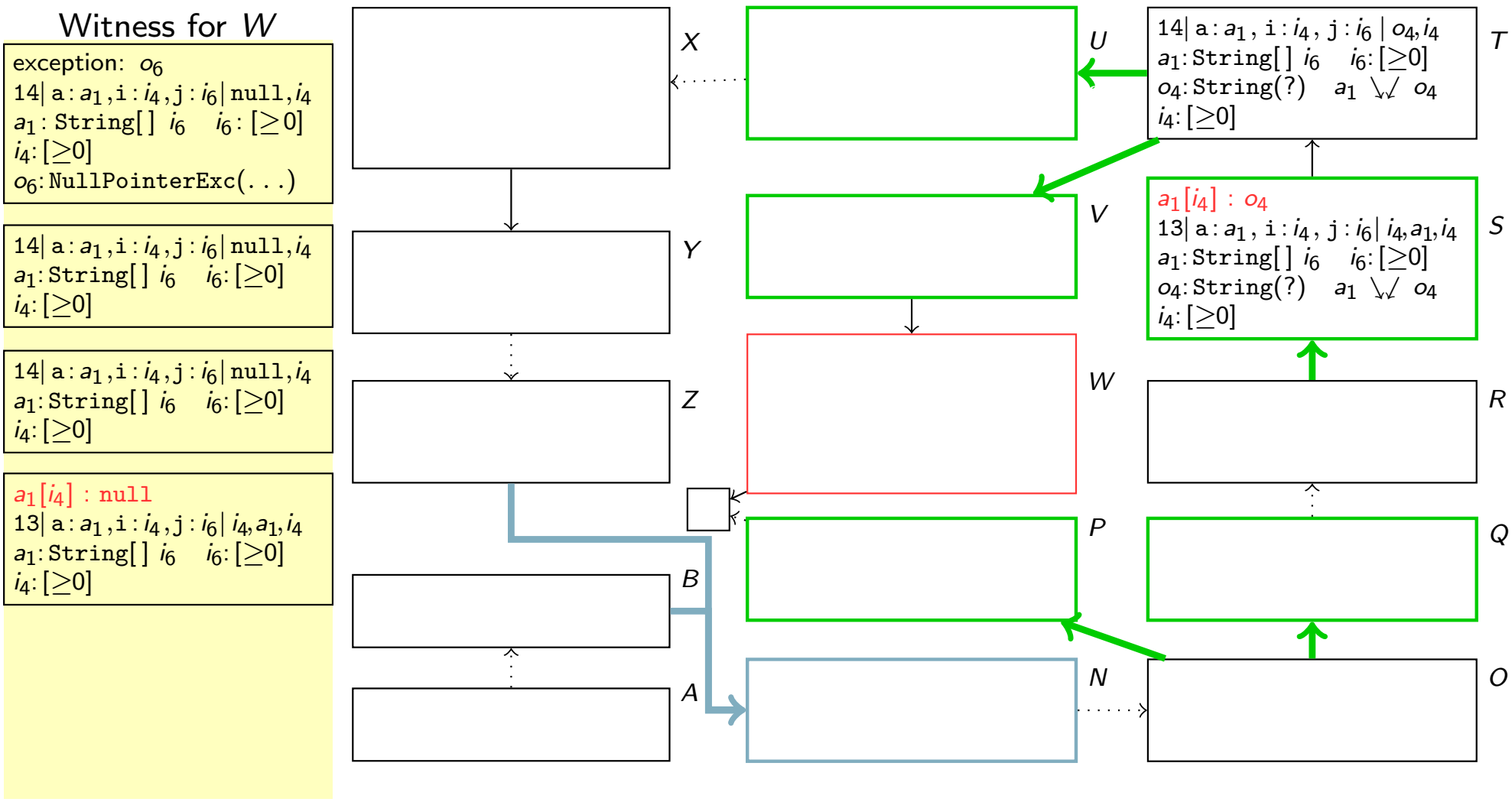

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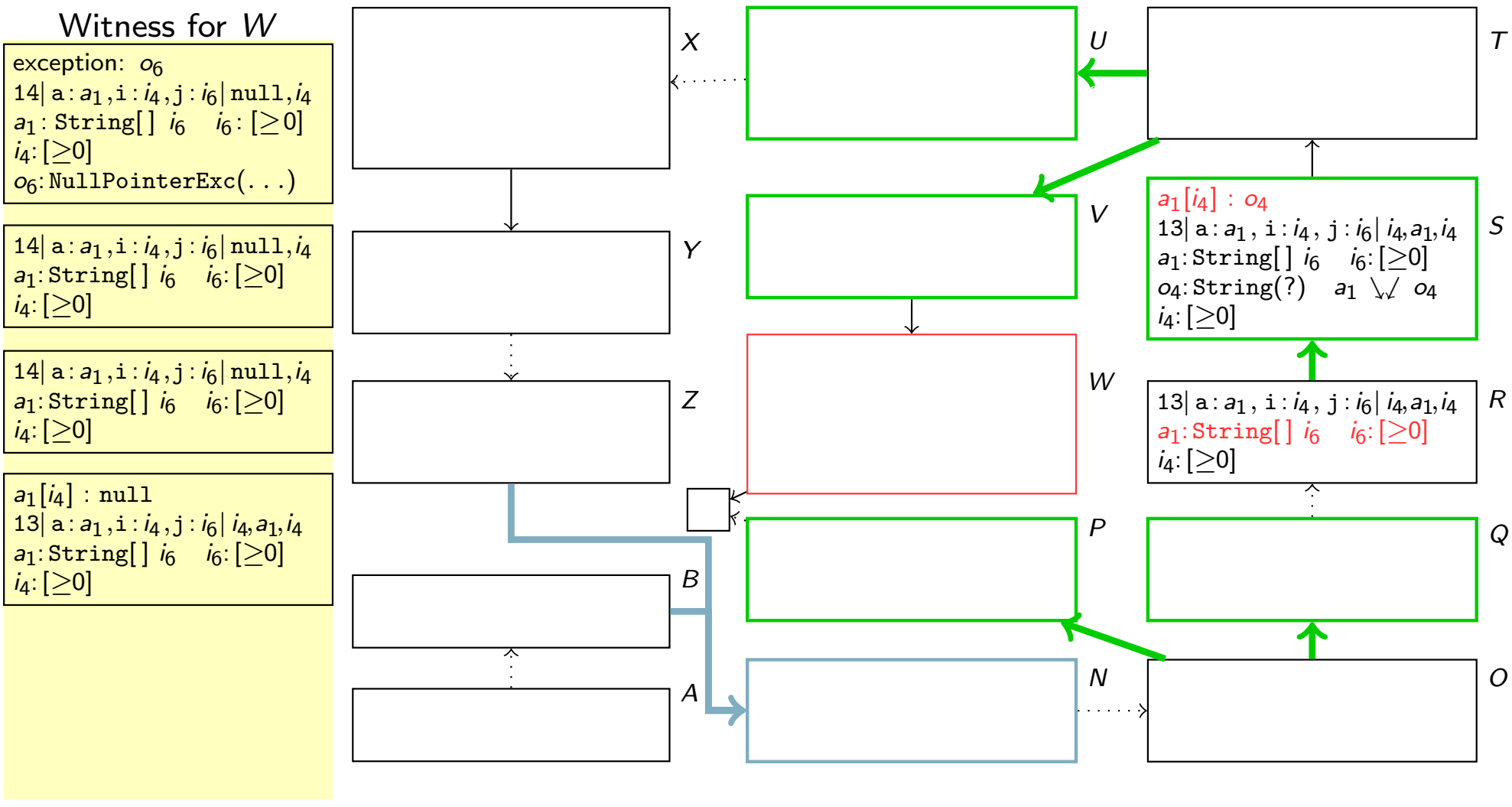
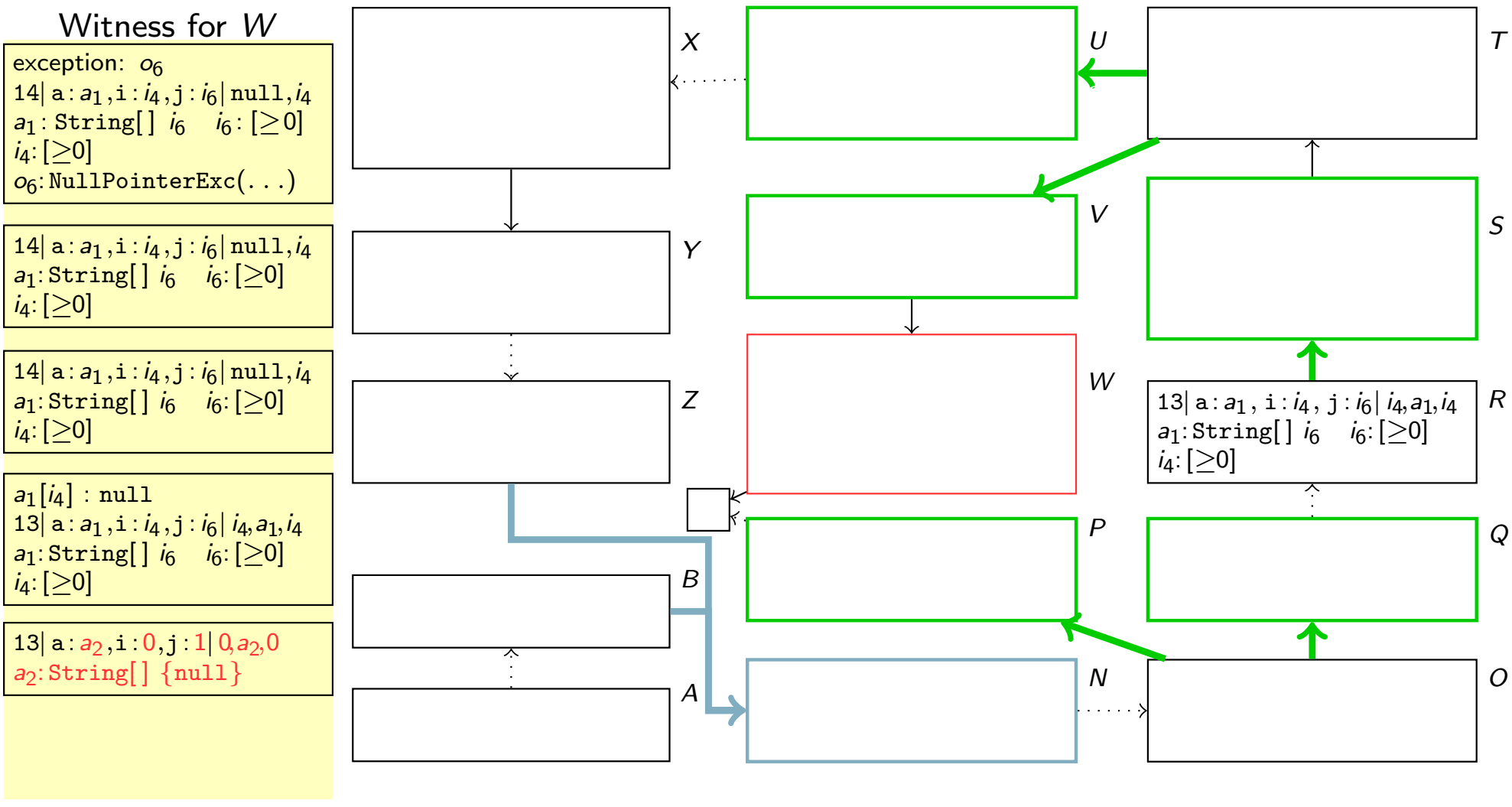
- S evaluated to T: Reverse evaluation

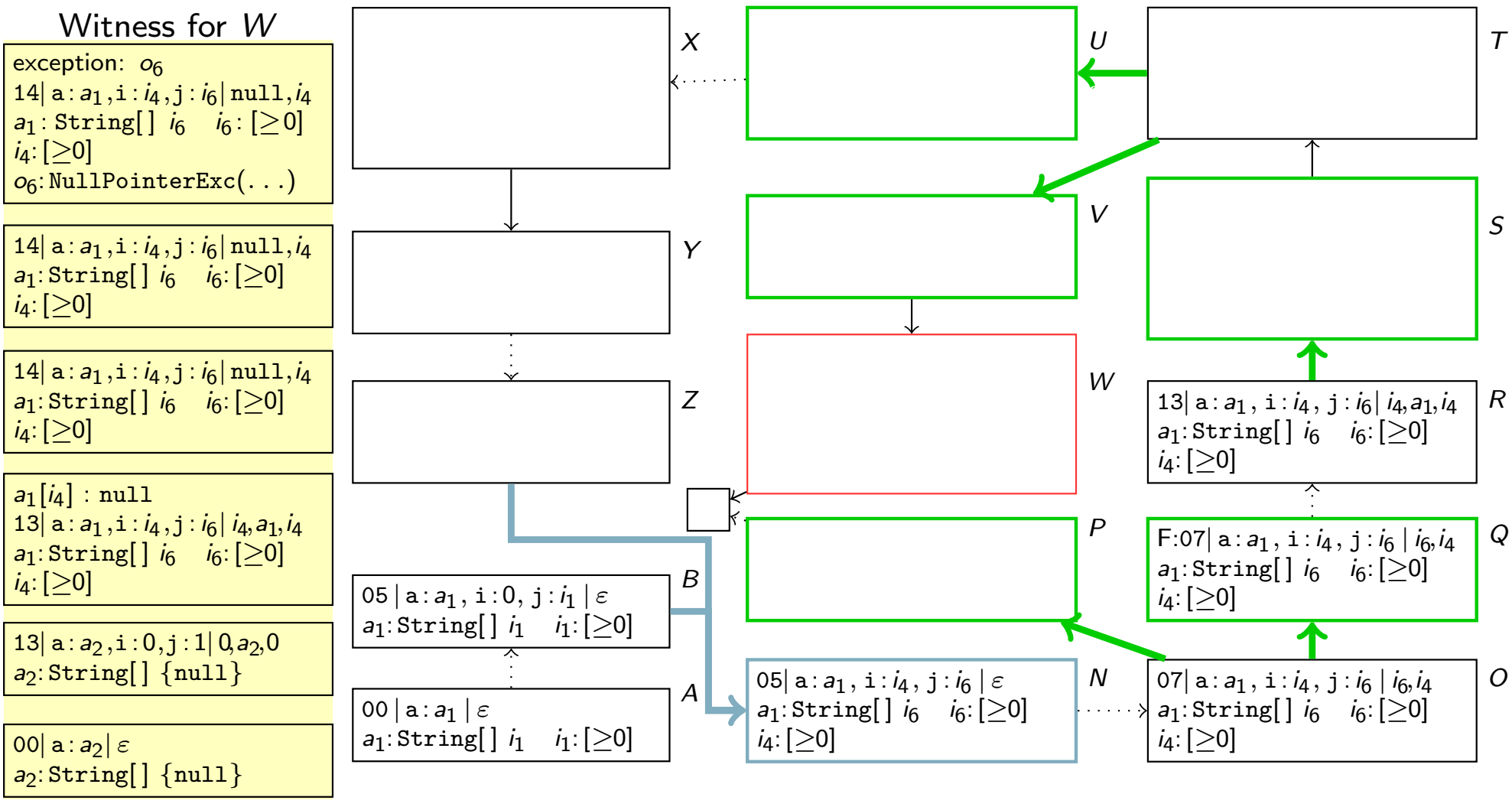


- R refined to S: Re-use current witness



- R refined to S: Re-use current witness - No!
- a_1 too abstract to keep information

$\Rightarrow$ Instantiate array and index by concrete values



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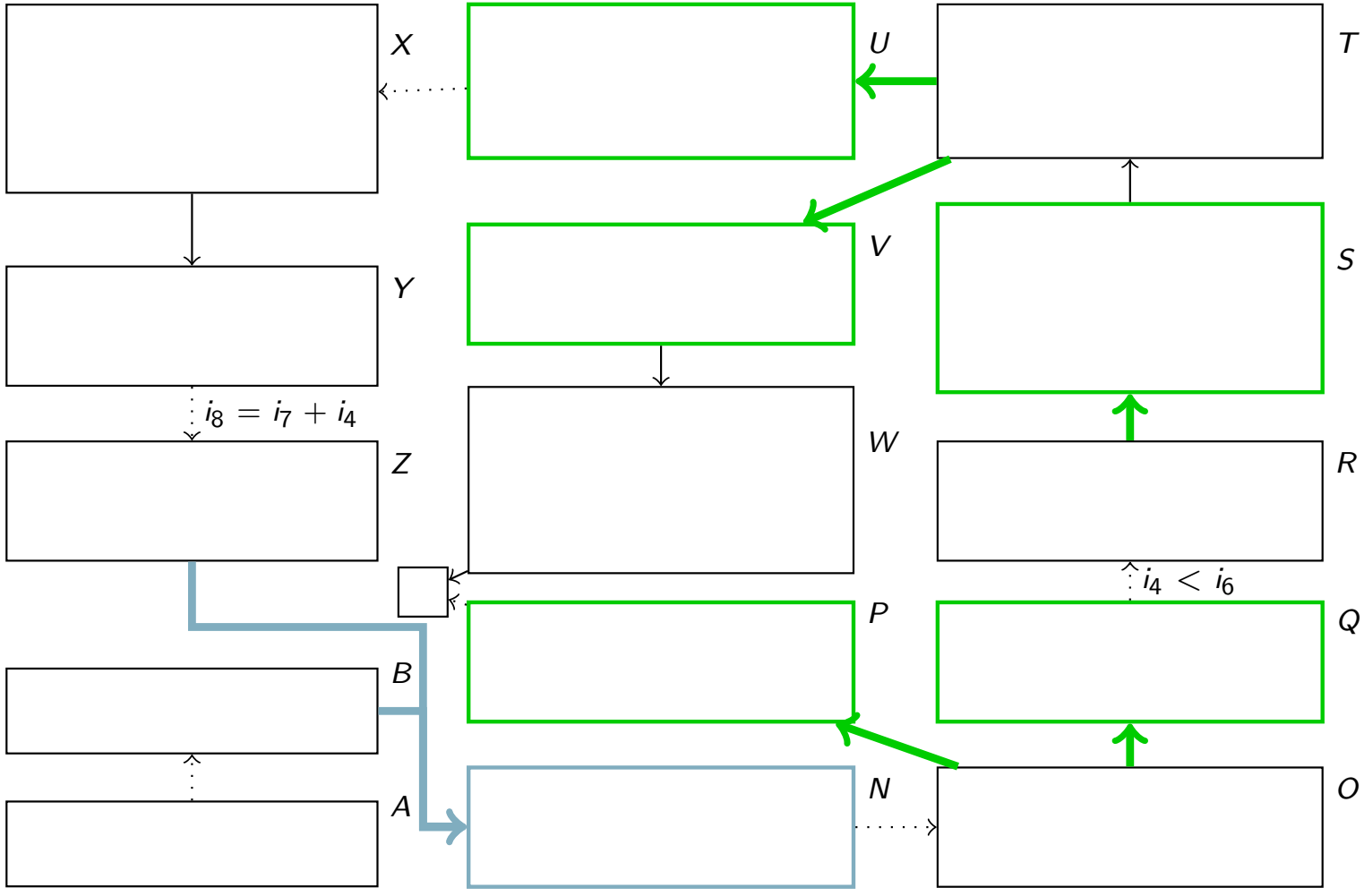
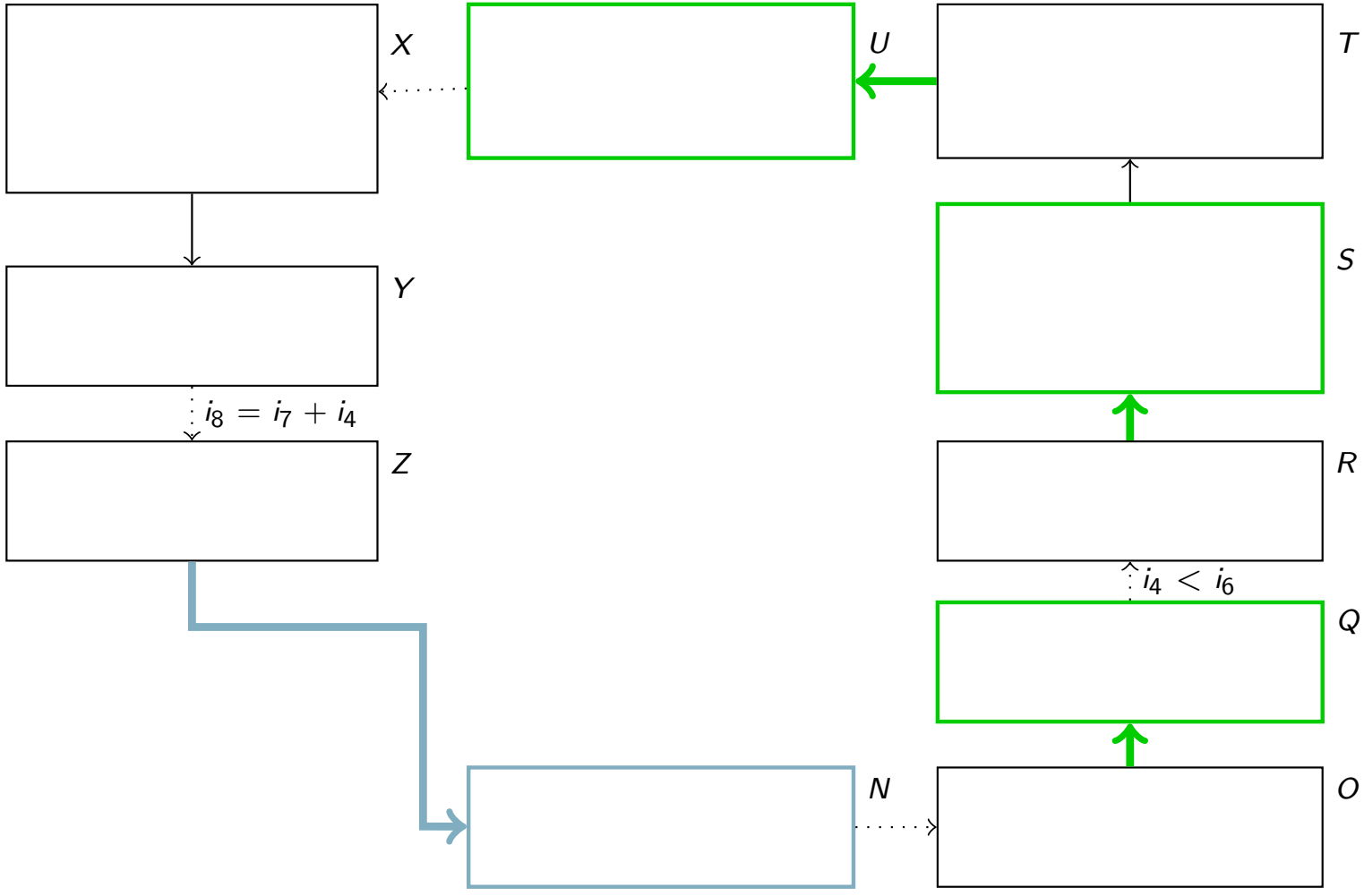


- Goal: Find state that is visited again and again



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- Heuristic: Integers: Find values by SMT
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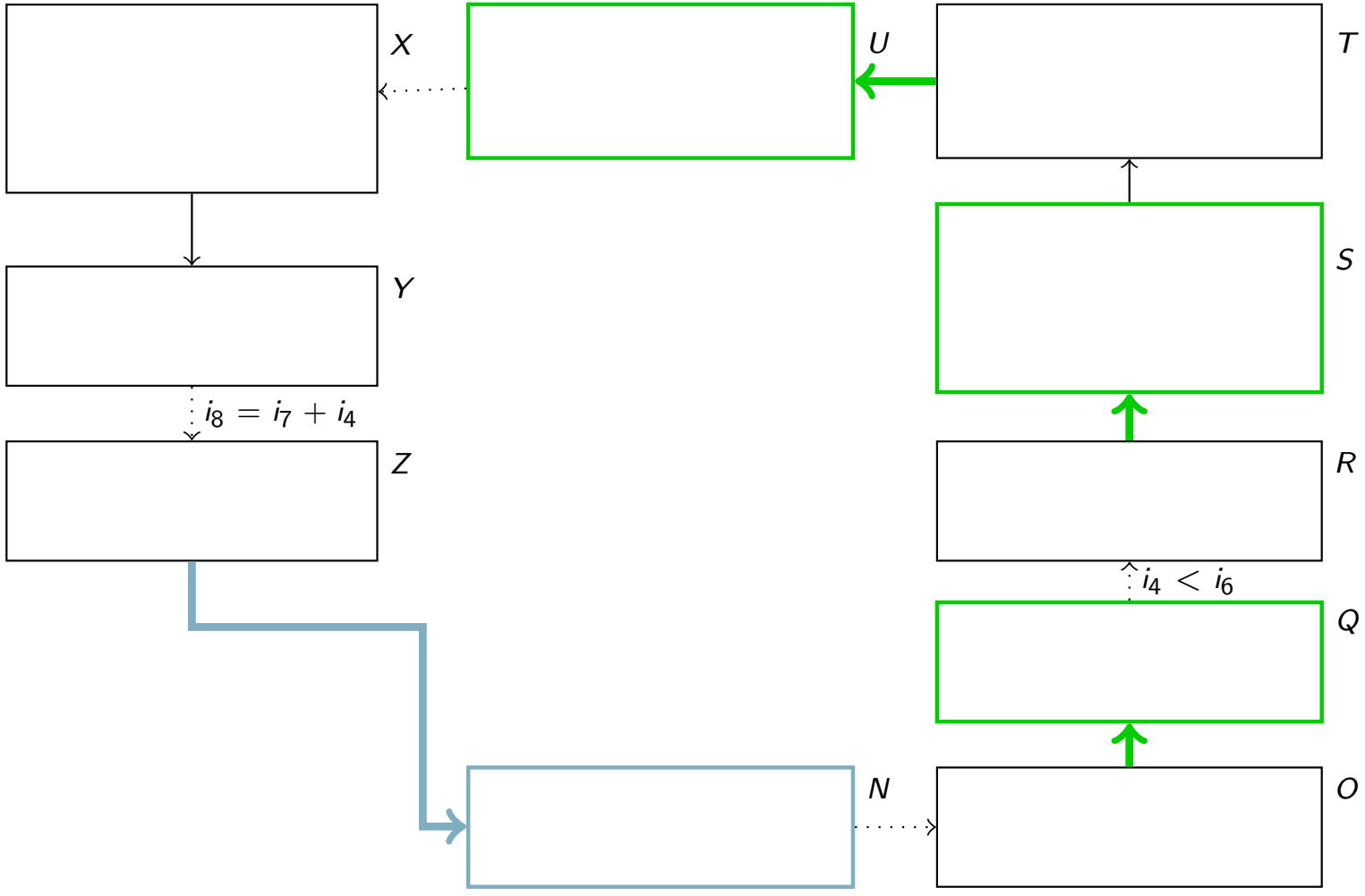

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$i_4 < i_6$
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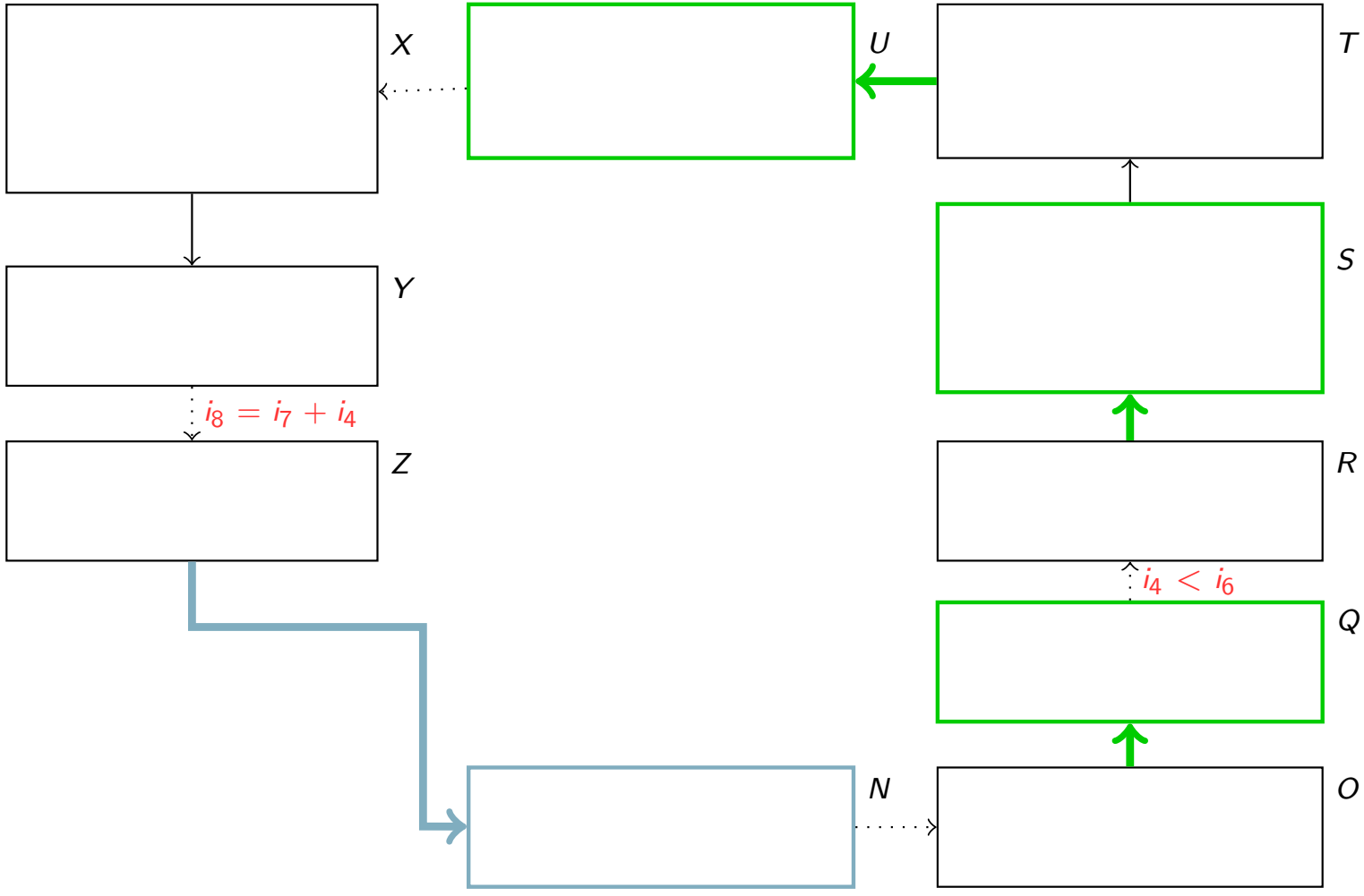

Find values by SMT

- Use conditions on edges

$$
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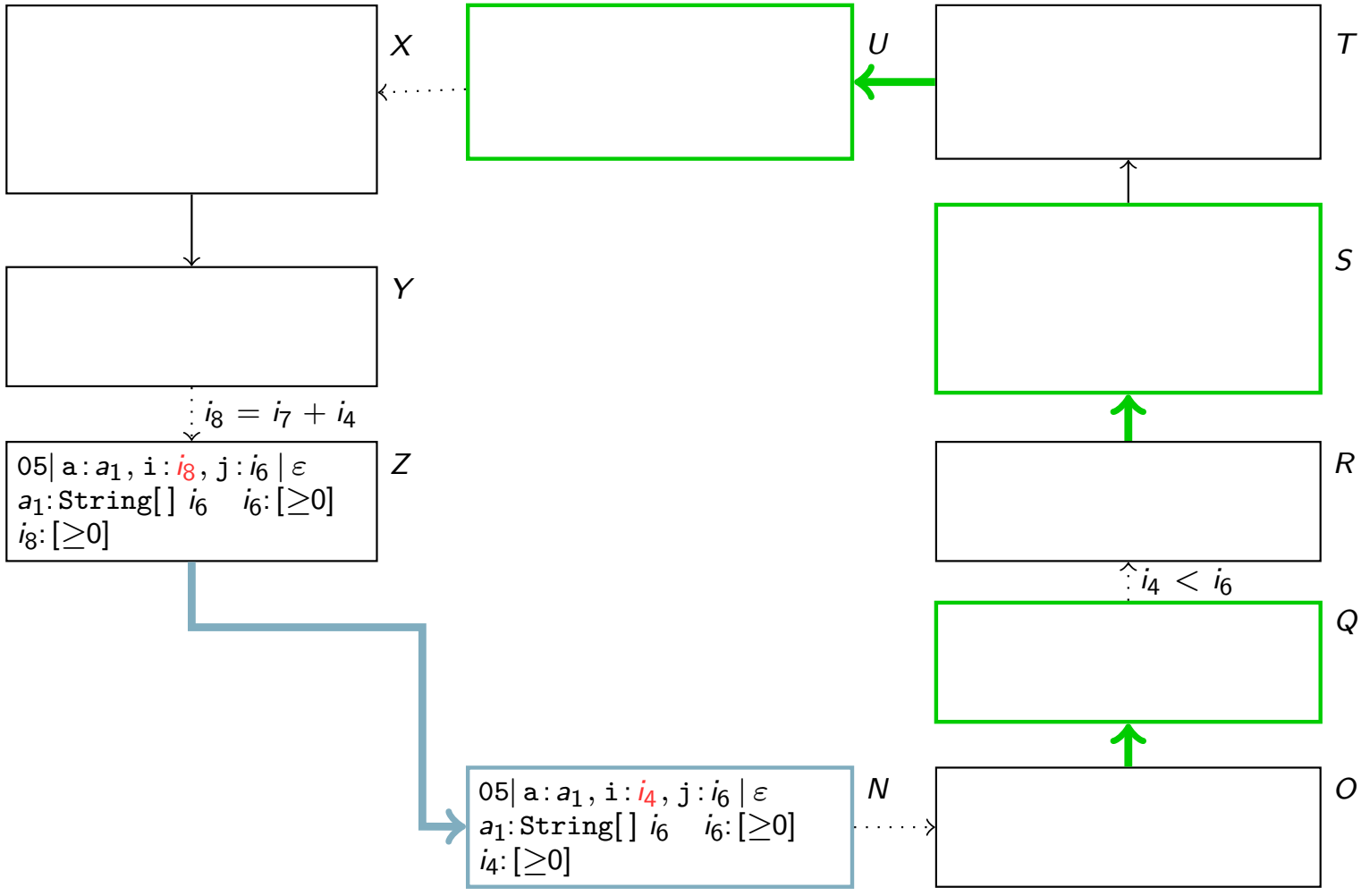

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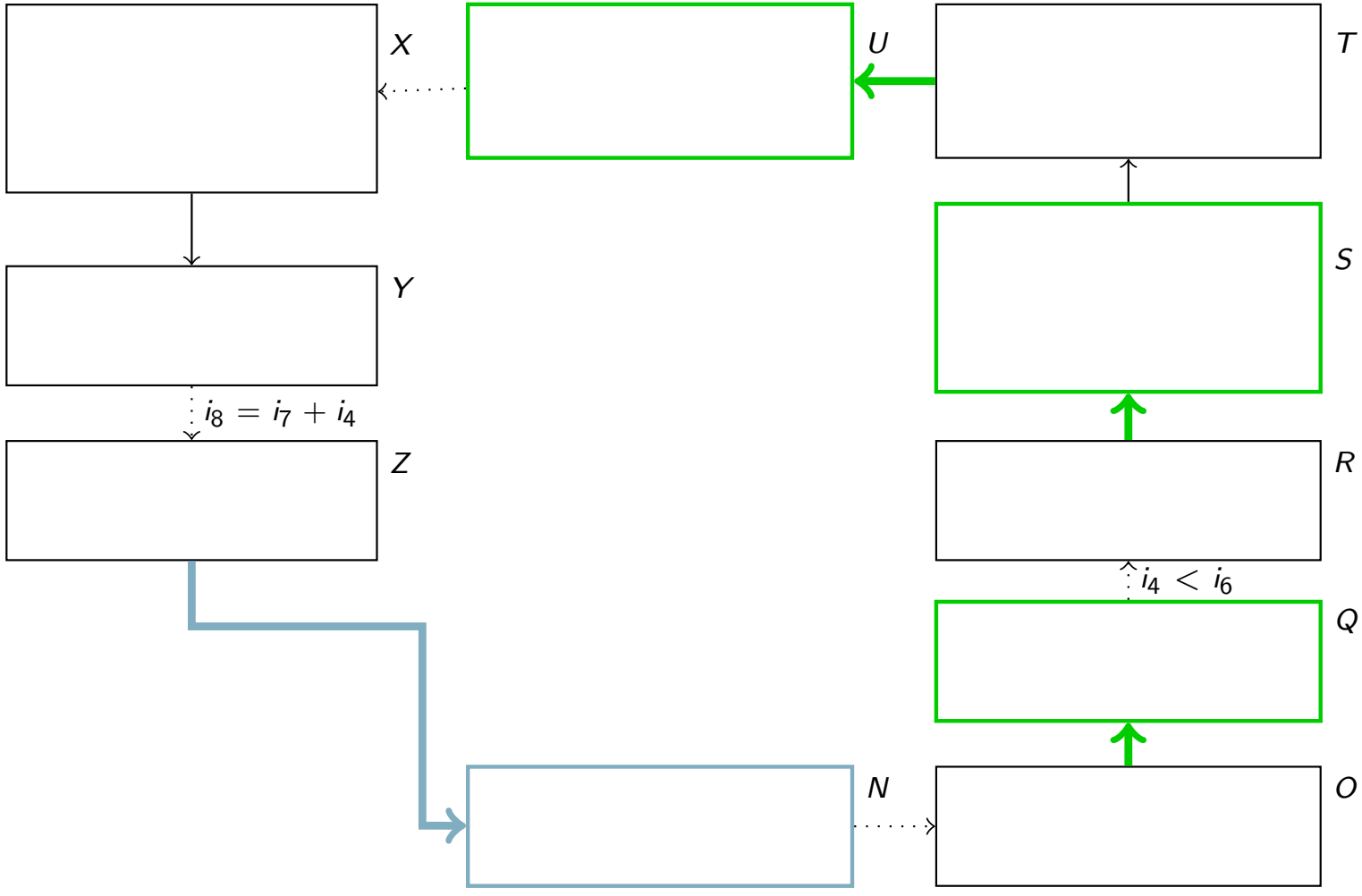

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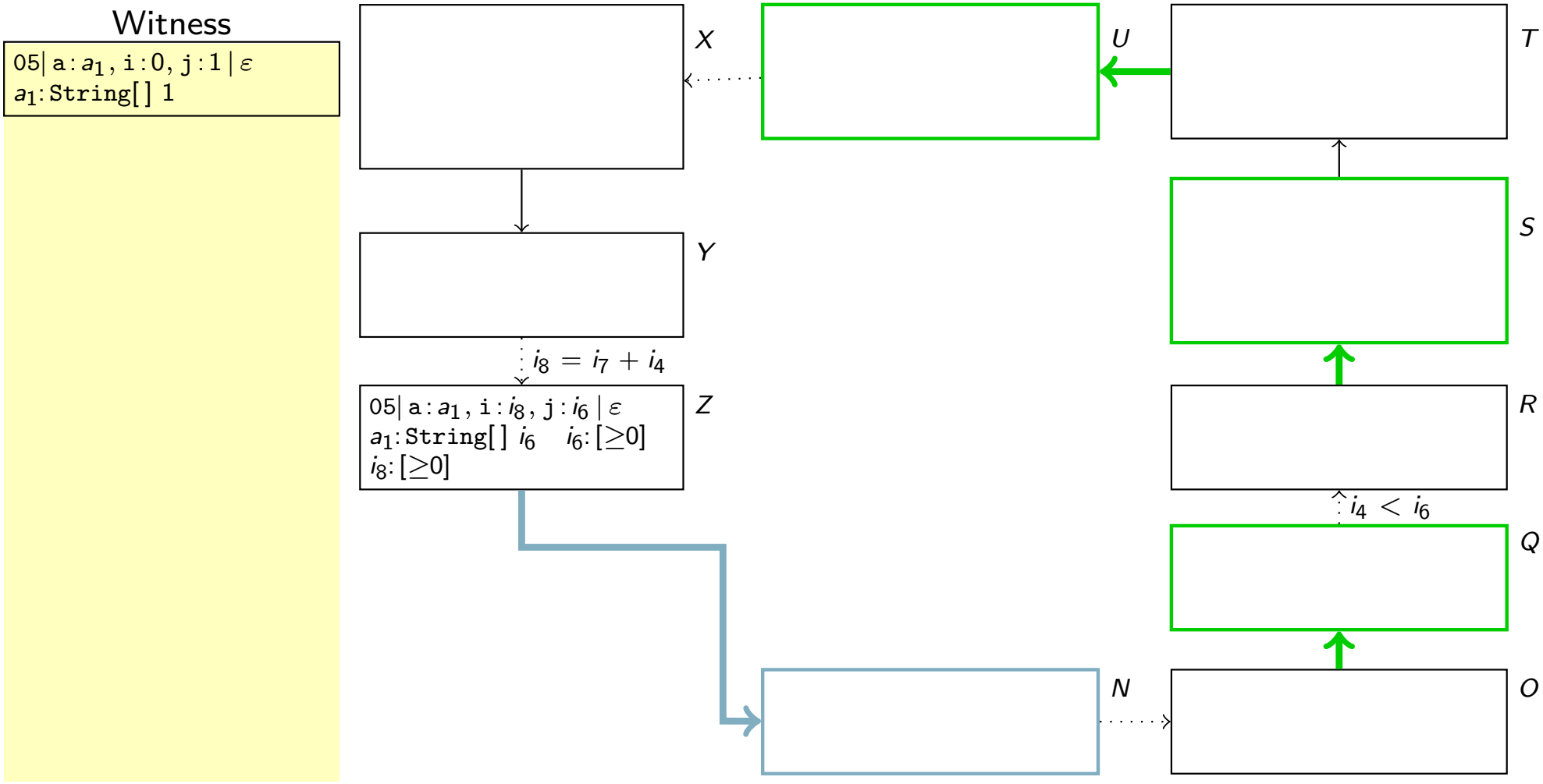

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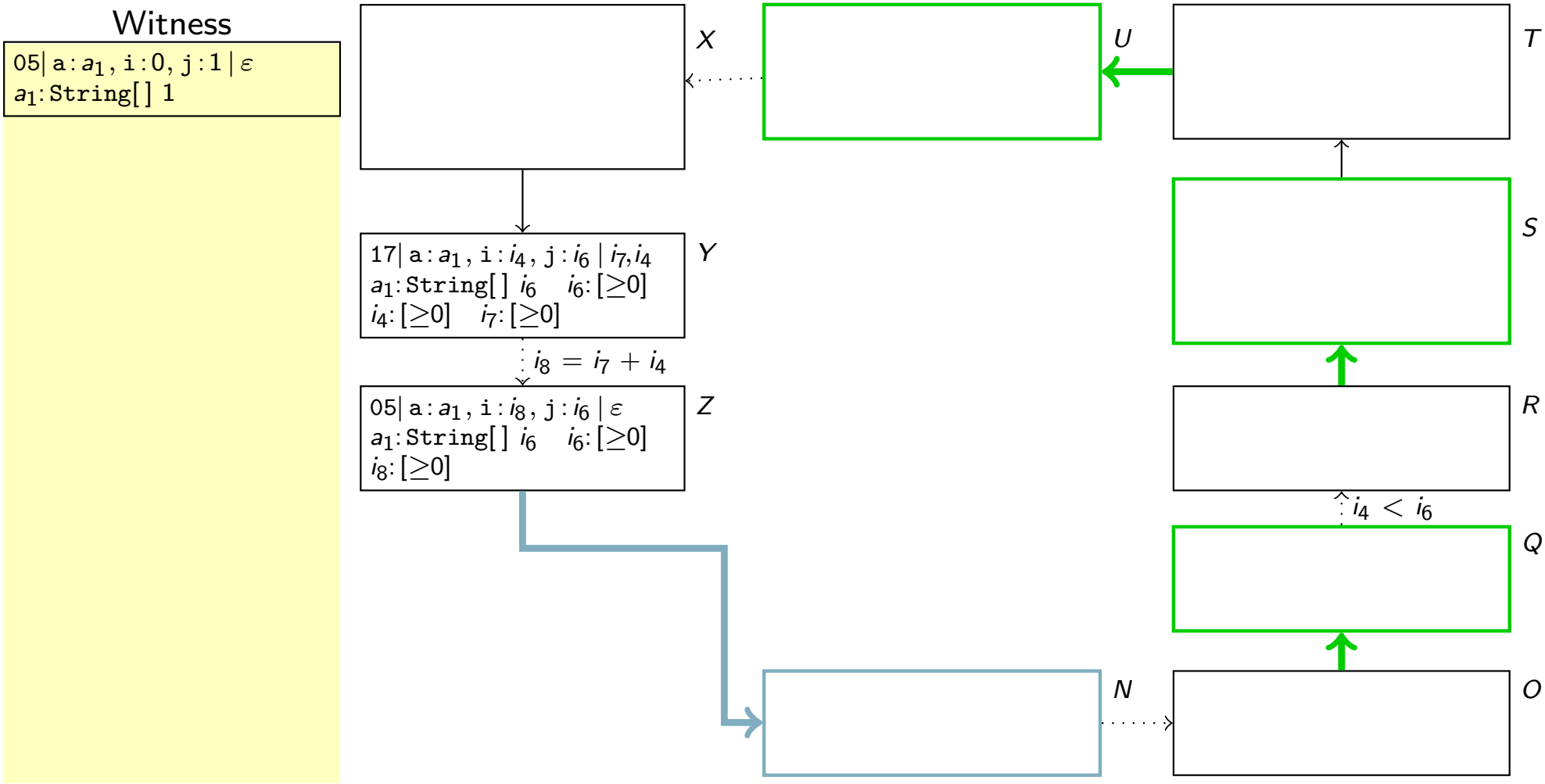

Find values by witness generation

- Instantiate last loop state with integer solution
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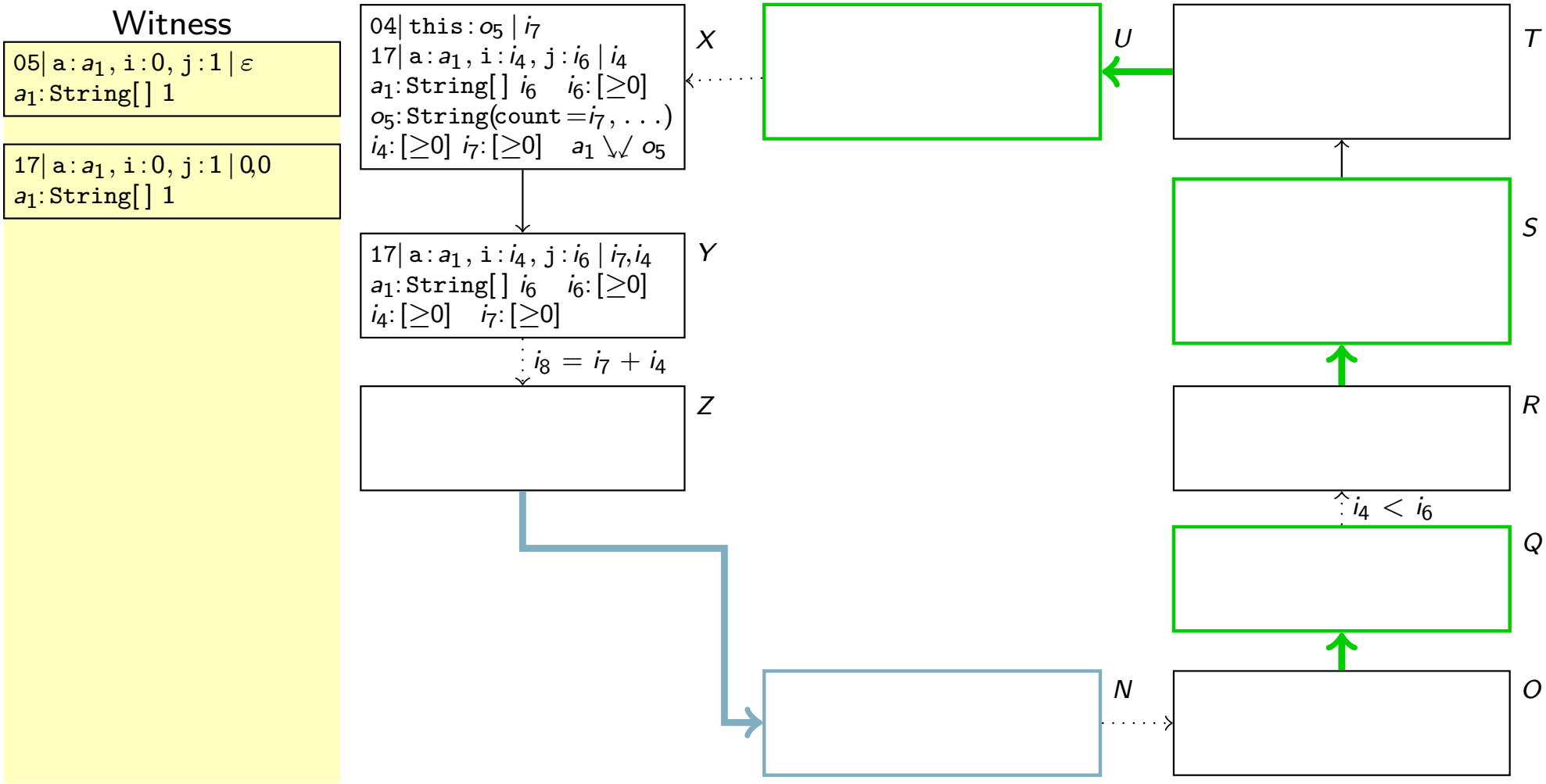

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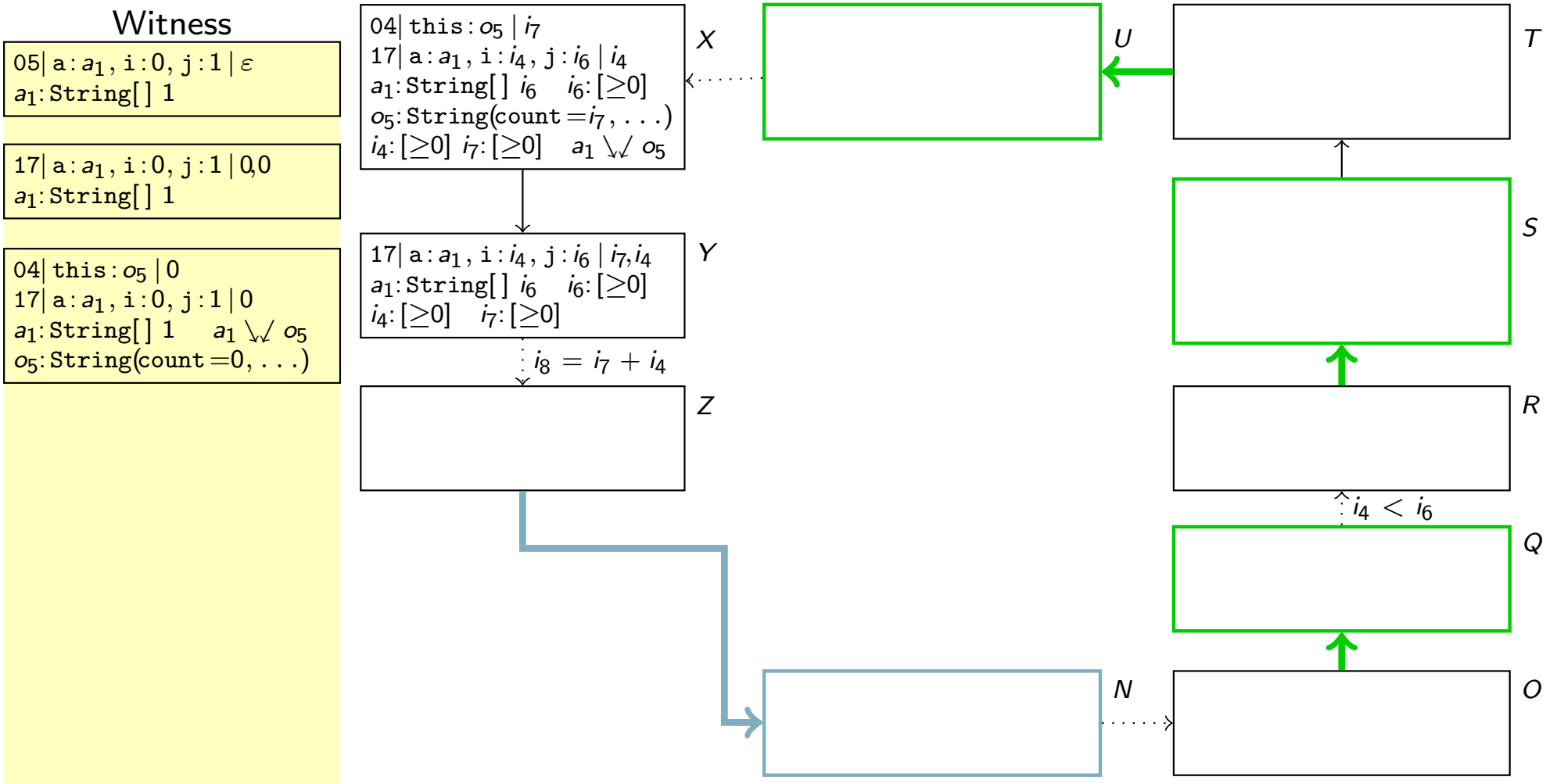

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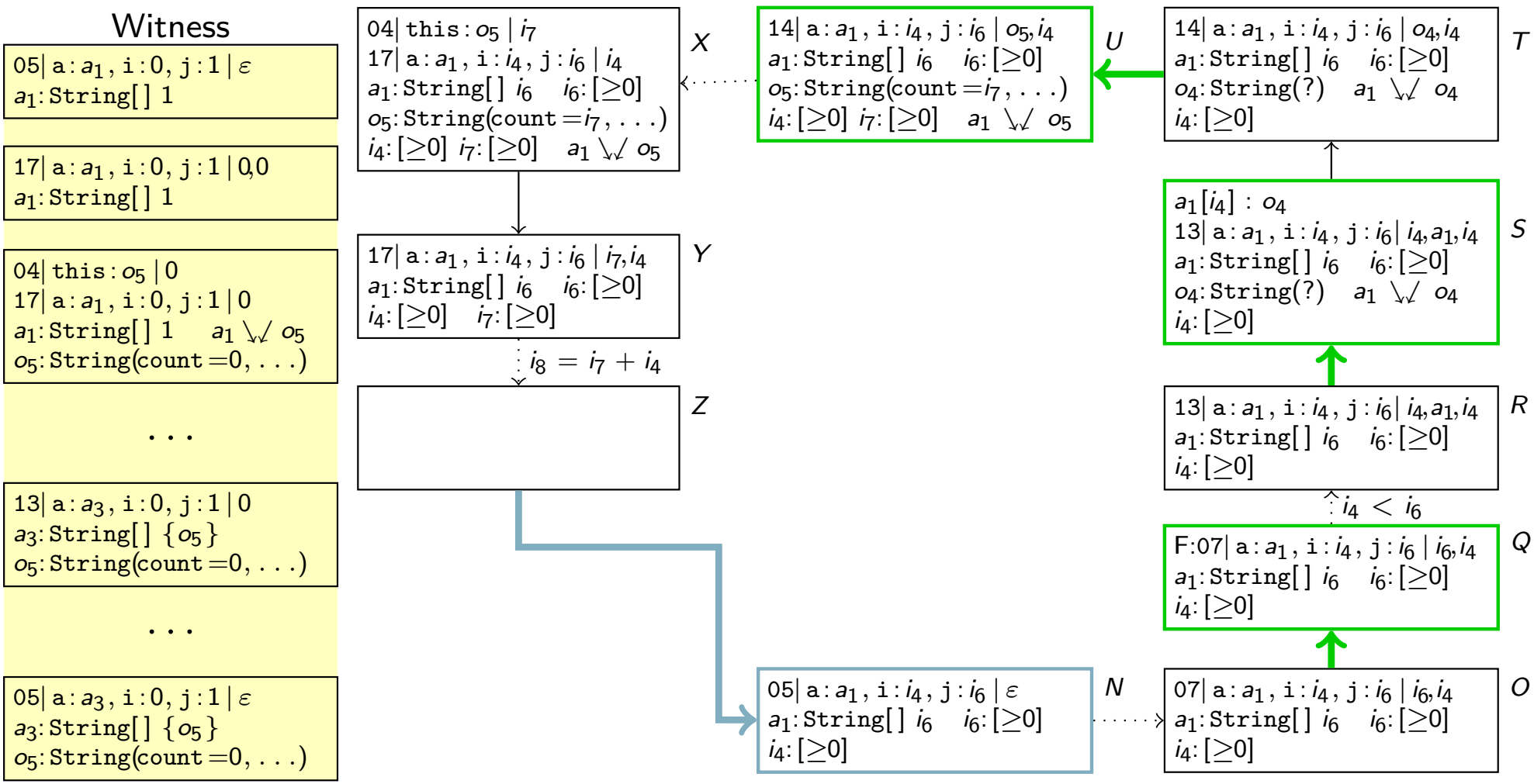

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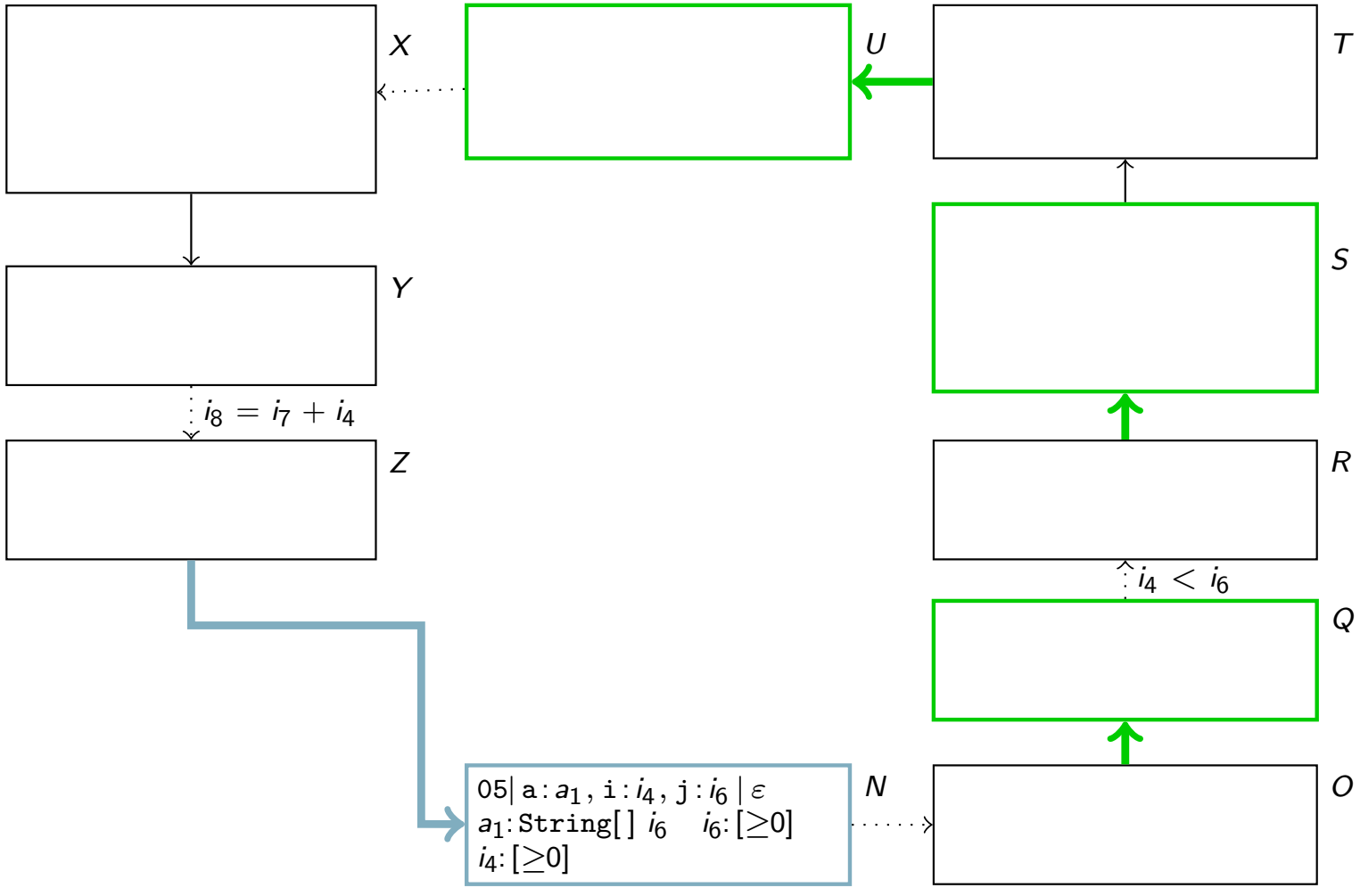
Witness



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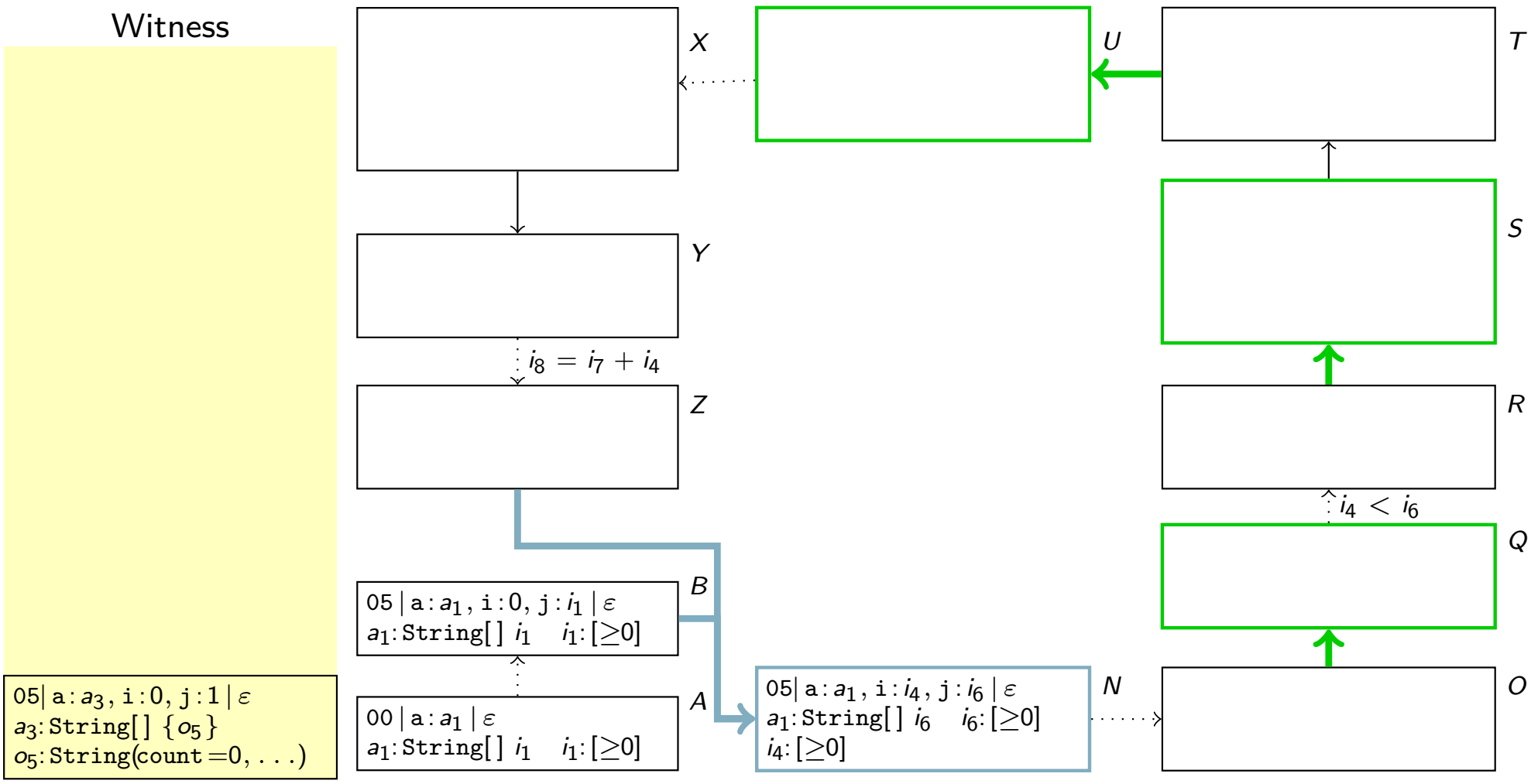

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00| a : a_3 | ε
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Witness

- Find start state witness

Other work

Already done:

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- Non-looping Non-termination
- Termination analysis

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Extensions:

- Use other SMT theories
- Use source code annotations
- ...

Non-termination analysis of JBC

- Implemented in AProVE for full single-threaded Java

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	Y	**N**	**F**	**T**	**R**	**Y**	**N**	**F**	**T**	**R**
AProVE-No	1	51	0	3	5	204	30	12	24	11
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Yes, **N**o, **F**ailed proof, **T**imeout, **R**untime (average)

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http://aprove.informatik.rwth-aachen.de/eval/JBC-Nonterm